

COMPARATIVE PERFORMANCE OF POLYPHOSPHATE
FERTILIZERS FOR THREE ROW CROPS

by

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INTRODUCTION

Phosphorus as a macronutrient is becoming increasingly important as irrigated areas in the Plains States are developed. With the fairly recent introduction of polyphosphate (PPP) fertilizers containing more than one P atom per molecule, several new questions have arisen. It is generally accepted that PPP materials are efficient carriers of P and have the advantage of lower freight costs per unit of P than conventional orthophosphates (OP) because higher P analysis fertilizers can be manufactured. The introduction of PPP materials has also been instrumental in the rapid growth of the liquid fertilizer industry due to both higher P concentrations in liquids through PPP use and to greatly reduced sludge problems because of the ability of PPP to sequester iron and magnesium impurities.

Under most agronomic conditions, most agronomists consider PPP to be at least equal to OP in ability to supply P to plants. Some have suggested that PPP may in fact be a superior source of P. Some question has arisen however, concerning the agronomic effectiveness of PPP on high pH, calcareous soils. A possibility exists that under these conditions, PPP may form highly insoluble reaction products that would limit the availability of P to the plant (Subbarao and Ellis, 1975). Consequently, the need exists to further evaluate tripolyphosphates (TPP), pyrophosphates (PP), and OP under soil conditions of high pH and free calcium carbonate.

Claims of increased Zn uptake when Zn is applied with liquid ammonium polyphosphate (APP) have been made in some cases. This is a possibility because PPP fertilizers are known to sequester certain metal nutrients. Further evidence is needed to substantiate this claim, however.

To answer these unresolved questions, several field and growth chamber studies were initiated. Objectives of the field studies were: (1) to determine effects of several PPP fertilizers and an OP fertilizer at several P rates

on grain yields and tissue P and Zn concentrations, and (2) to determine effects of Zn application in combination with the various P fertilizers on grain yields and tissue P and Zn composition. Identical objectives were assigned to growth chamber investigations, but more soils were used including some from the Mississippi River Delta in northeastern Arkansas and western Tennessee.

REVIEW OF LITERATURE

Several researchers have compared the agronomic effectiveness of PPP and OP fertilizers using several crops. Results of these comparisons have not been consistent.

Using cabbage (Brassica oleracea capitata) as a test plant, Hansel (1968) indicated that the total yield and weight per head increased about 5 percent when APP was used as compared to ammonium orthophosphate (AOP). Work conducted under flooded and non-flooded soil conditions indicated that superphosphate, an OP source, and liquid APP were more effective P sources than solid APP under flooded conditions for lowland rice (Oryzaea sativa). No differences were observed between superphosphate and liquid or solid APP under non-flooded conditions (Cherian, Paulsen, and Murphy, 1968).

In some Nebraska studies, inconsistent results between locations were observed when AOP was compared to APP for corn (Zea mays L.). Differences were attributed to the many types of soils used. Only about half of the locations studied responded to added P in terms of increased yields and/or tissue P content (Penas, 1967).

Studies of APP and AOP as P sources for barley (Hordeum vulgare L.) showed that on 60 of 98 soils studied, P uptake was greater from AOP treatments than from APP (Sutton, Gunary, and Larsen, 1966). This effect was considered to be due to soil temperature differences, with low temperatures being associated with low P uptake from APP treatments. Soil temperatures lower than 30 to 35 C were suggested as possibly restrictive to APP hydrolysis and production of OP ions, the form in which P is absorbed by the plant. Sutton and co-workers stated that the 30 to 35 C temperature range is probably the optimum for PP hydrolysis.

An early experiment comparing sodium OP and PP as P sources for barley, wheat (Triticum aestivum), and oats (Avena sativa) concluded that these sources were equal in their ability to supply P to the plant (Kida, 1923).

Kida also conducted studies with rice, buckwheat (Fagopyrum sagittatum), radishes (Raphanus sativus), barley, and oats, using P sources of various solubilities. He determined that the solubility of the P sources affected the availability of P more than did the source of P.

Other work with several types of P fertilizers on a calcareous soil was reported by Bennett, Longnecker, and Gray (1954). They found that the P materials with a high percentage of water soluble P were of much higher value in increasing crop yields. When considering all crops grown over a five year period, sodium pyrophosphate and monoammonium phosphate (MAP) were the two outstanding sources of P, even though no statistically significant differences were observed.

Sutton and Larsen (1964) researched P sources for ryegrass (Secale cereale) comparing OP and PP. They used two soils, a sand (pH 4.0) and a sandy loam (pH 7.2). The ryegrass was harvested at two-week intervals. On the sand soil at all harvesting dates, the greatest P uptake occurred from OP. Explanations ventured suggested that the PP material was not hydrolyzed for an extended time; and although some P uptake occurred from the PP, it was less than that from OP. Plants from the higher pH sandy loam soil contained more P from OP than PP at the first harvest. They concluded that more rapid hydrolysis of PP had occurred under those conditions so that after the first harvest, no differences between sources occurred.

Kansas workers studied MAP and APP in solution cultures under growth chamber conditions using corn as the test crop. MAP was slightly more effective than APP only under low Zn conditions (Ganiron, Adriano, Paulsen, and Murphy, 1969). In a Michigan study with potatoes (Solanum tuberosum), yields tended to be slightly lower with APP than MAP (Christenson and Doll, 1968).

Terman and Engelstad (1966) studied APP and diammonium phosphate (DAP) as P sources for corn in both field and greenhouse situations. They reported that grain yields and leaf P content of the greenhouse grown corn were com-

parable regardless of P source when the rate of P application was 73 kg/ha. At higher P rates, P content of leaf tissue was greater with APP than DAP. Yields of field-grown corn were reported as not being significantly different.

In still another study comparing APP and MAP in field and growth chamber situations, different results were observed by Webb (1970). He found in several field studies involving soils of slightly acid to basic pH that the trend was toward superiority of APP over MAP in yield responses, although the differences were not statistically significant. Differences between liquid and solid APP were not significant in terms of leaf P concentrations or grain yield.

APP and AOP were compared as P sources for tomatoes (Lycopersium esculentum) grown on a calcareous soil in the greenhouse (Stroehlein, Sabet, and Clementz, 1968). They noted no differences between the two sources, even though a response to added P was observed with both APP and AOP. A similar statement concerning the effectiveness of AOP and APP in terms of corn yield and ion uptake on soils of pH less than 7.0 was attributed to Dobson, Wells, and Fisher (1970). When Stroehlein et al., used barley as the crop, a response to added P was observed on three of four soils used. In this case, AOP produced better results than APP. Since this experiment was conducted during the winter, the authors stated that the low soil temperatures may have reduced the rate of hydrolysis of APP. With the experiment conducted as a double cropping system using barley as the first crop and tomatoes as the second, APP gave significantly better results than AOP on the tomatoes only.

In a study using pea beans (Phaseolus vulgaris L.), yields were greater when AOP was used as compared to MAP, whether or not zinc was included in the fertilizer (Judy, Melton, Lessman, Ellis, and Davis, 1965).

Blanchard and Hossner studied sodium salts of OP and PP as P sources for corn in a growth chamber (1969). They used three rates of P and noted a response to increasing P in terms of increased dry matter and P content of

corn. Dry matter production increased from both OP and PP usage. PP gave a slightly higher P uptake from the soil than OP. Data indicated that both PP and OP were strongly adsorbed by the soil.

The effect of AOP and APP on corn growth at three rates of P application in a growth chamber experiment was determined (Subbarao and Ellis, 1975). A slightly acid and a calcareous soil were used. They recorded higher plant dry matter production on the slightly acid soil versus the calcareous soil at all levels of P application. The AOP source was superior to the APP source at a 36 ppm P application rate on the calcareous soil and at 9 and 18 ppm P rates on the slightly acid soil. With P uptake under consideration, the plants grown on the calcareous soil took up less P than plants grown on the slightly acid soil. The AOP source was superior to APP in the slightly acid soil at all P rates but only at the high rate of P application on the calcareous soil. Soil analyses conducted at the conclusion of the study indicated that the amount of Bray P-1 extractable P on the slightly acid soil increased for all rates of P application, and there were no differences between AOP and APP sources. There was a difference in extractable soil P between AOP and APP in the case of the calcareous soil. APP applications did not increase available soil P while AOP did, suggesting formation of more insoluble compounds by APP.

Some North Carolina research indicated that PPP was as effective as superphosphate in the ability to supply P for plant growth (Miner and Kamprath, 1971). They stated that although the condensed phosphate ions are held more strongly by soil materials than OP ions, there appears to be no difference in their effectiveness as P sources.

In still another study, APP and MAP were compared in the field (Murphy, Webb, Adriano, and Ganiron, 1968). A yield superiority of banded APP over banded MAP was noted. No differences were seen between carriers in terms of influence on plant composition.

Generally, neither ortho nor polyphosphates exhibit a consistent advantage in increasing yield or phosphorus uptake by plants. Some situations may exist in which one or the other may be superior, but these conditions do not seem to be well defined.

Assuming that the plant absorbs phosphorus in the ortho form, hydrolysis of PPP fertilizers would have to occur before absorption could take place. There is general agreement that the plant does indeed take up the majority of its phosphorus in the ortho form. Research conducted with potatoes indicated that OP was preferentially absorbed over PP, although PP was absorbed to a certain degree without preliminary hydrolysis (Conesa, 1969). This conclusion was supported by Sutton, Gunary, and Larsen (1966). They stated that the value of PP as an immediate source of P is dependent on its rate of hydrolysis to OP units.

Certain factors may either enhance or inhibit hydrolysis of PPP fertilizers to OP ions. Many researchers have studied pH and biological activity effects on PPP hydrolysis. Effects of several factors on the rate of PPP hydrolysis are listed below (Van Wazer, 1958):

<u>Factor</u>	<u>Approximate effect on rate of hydrolysis</u>
1. Temperature	10^5 - 10^6 fold faster from freezing to boiling
2. pH	10^3 - 10^4 fold slower from strong acid to base
3. Enzymes	As much as 10^5 - 10^6 fold faster
4. Colloidal gels	As much as 10^4 - 10^5 fold faster
5. Complexing cations	Very many fold faster in most cases
6. Concentration	Roughly proportional
7. Ionic environment in the solution	Several fold change

Other researchers have noted the effects of pH on the hydrolysis of tripolyphosphate (TPP) and PP. The hydrolysis of TPP was found to decrease at a pH of 9 compared to a pH of 5 and 7 in creek bottom sediments, but the rate of PP hydrolysis increased with increasing pH (Domingo, 1974).

Others showed that as pH increased, hydrolysis rate of PP increased (Sutton and Larsen, 1964) and that the rate of TPP hydrolysis was more rapid between pH 7.7-6.8 than either higher or lower pH (Blanchar and Hossner, 1969).

In contrast, when the soil pH was increased above 7, PP hydrolysis was found to markedly decrease (Gilliam and Sample, 1968). This phenomenon was supported by data of Hossner and Blanchar (1969).

An optimum pH apparently exists for phosphatase activity as well as for other enzymes. Phosphatases were found to be most active at pH 4.2-4.5 (Chunderova, 1970), but it is not known that if pyrophosphatase activity is maximized at that pH range.

Effects of biological activity on PPP hydrolysis have been reported frequently. The PP hydrolysis in some Nigerian surface soils was described to be faster than in subsoils due to higher microbial activity and organic matter of the surface soils (Juo and Maduakov, 1973). This conclusion was supported by evidence that PP hydrolysis was proportional to CO_2 production in a given soil at a given temperature (Sutton, Gunary, and Larsen, 1969).

The destruction of the microbial population and residual phosphatases by autoclaving markedly slowed the hydrolysis of PP in a Norfolk loamy sand soil. Fumigating soil with CH_3Br to retard microbial activity also decreased PP hydrolysis. This reduction was attributed to the destruction of phosphatase enzymes necessary for PPP hydrolysis (Gilliam and Sample, 1968).

Sutton and Larsen (1964) considered enzymatic hydrolysis to be more important than pH, temperature, and other effects on PP hydrolysis, concluding that there must be a direct relationship between total biological activity and pyrophosphatase activity. They suggested that in soils with high biol-

ological activity, PP would not persist long enough for differences between OP and PP to affect plant P uptake and subsequently crop growth.

Reports of combined effects of pH and biological activity are available. Gilliam and Sample (1968) noted that PP hydrolysis decreased with increasing soil pH above 6.2, except in autoclaved samples, where there was no effect of pH changes on hydrolysis. This reduction in PP hydrolysis rate with increasing soil pH in non-sterile soils may be due to changes in the microbial population at the higher pH's or to lowered effectiveness of pyrophosphatase produced at higher pH's. Evidence supporting this contention is cited by Chunderova (1970) and Koche (1950). It is possible that the differences in pH effect on rate of PP hydrolysis may be a result of changing the pH of a particular soil (Gilliam and Sample, 1968) rather than using soil at its unaltered native pH values (Sutton and Larsen, 1964).

Blanchar and Hossner (1969) reported that phosphatase enzymes liberated by microorganisms increased the rate of trimetaphosphate hydrolysis by as much as 10^5 - 10^6 times. They also indicated that the relationship between soil biological activity and increased PP hydrolysis and the higher biological activity in the rhizosphere may result in accelerated PP hydrolysis near root surfaces. These factors were offered as possible explanations of PP abilities to occasionally supply more P to plants than OP.

Philen and Lehr (1967) studied both pH and phosphate species effects on hydrolysis, concluding that the rate and extent of hydrolysis decreased as pH increased. They also noted that TPP hydrolyzed more rapidly than PP.

Subbarao (1975) recently investigated rates of PPP hydrolysis. He reported that TPP generally hydrolyzed faster than PP. Higher hydrogen ion concentrations increased the rate of hydrolysis of PP and TPP. He also reported that uncatalyzed hydrolysis of PPP would be slow at normal soil temperatures.

The mechanism of PP and TPP hydrolysis and the relative ability of corn

and soybean (Glycine max) roots to accomplish hydrolysis of these materials in solution was also studied by Subbarao (1975). He found that hydrolysis of PP and TPP occurred faster in the presence of corn roots than soybean roots. He suggested that hydrolysis of PP released during TPP hydrolysis in solution occurred immediately in the presence of plant roots. In soils, Subbarao noted that PP may precipitate and markedly reduce its hydrolysis to OP. When TPP hydrolyzes, a third of it is converted to OP and the remaining two-thirds to PP. This OP produced does not precipitate and so may furnish P to plants in early growth stages. The PP may eventually hydrolyze and supply P for later growth. He suggested that in soils with low biological activity where PP hydrolysis is slowed, greater P uptake by the plant may occur with the use of a TPP versus a PP material. Subbarao also stated that non-enzymatic hydrolysis of both PP and TPP followed first order kinetics and would be extremely slow under normal soil pH and temperature conditions.

Racz and Savant (1972) studied the rate of potassium pyrophosphate hydrolysis in a non-calcareous soil under both field capacity and flooded soil moisture conditions. They found that initially, both the flooded and field capacity soil hydrolyzed PP at a rapid rate. However, after three days incubation time, the flooded soil hydrolyzed PP at a faster rate than did the soil at field capacity. This difference was theoretically attributed to an increase in pyrophosphatase activity in the flooded soil since a separate investigation showed flooded soils to have higher pyrophosphatase activity than soils at field capacity after several days incubation. When PP was fixed by the soil, it hydrolyzed at a slower rate than when in solution. Water soluble or loosely bound PP hydrolyzed at a much faster rate than did water insoluble or strongly bonded PP.

While studying the mobility of various PPP species in a fine sandy loam soil, Hashimoto and Lehr (1973) observed significant effects of sodium, potassium, and ammonium cations on the solubilities and rates of dissolution

of different phosphate species. They also found that all of the PPP hydrolyzed rapidly to OP in the moist soil used.

The effect of temperature on triammonium pyrophosphate (TAPP) and MAP effectiveness was researched by Engelstad and Allen (1971). They found that when corn was grown in cool soil (16 C), MAP was a better source of P than TAPP. In a warm soil (24 C), there were no differences between the two materials.

Subbarao and Ellis (1975) recently reported on the reaction products obtained when AOP or APP materials were added to a slightly acid soil and a calcareous soil. When APP was added to the surface of the calcareous soil, $\text{Ca}(\text{NH}_4)_2\text{P}_2\text{O}_7 \cdot \text{H}_2\text{O}$ was present at both 16 and 28-week sampling periods. This product results in a limited availability of P to plants due to low water solubility. Additions of AOP produced $\text{Mg}_2\text{KH}(\text{PO}_4)_2 \cdot 15\text{H}_2\text{O}$ after 16 weeks and $\text{Ca}_4\text{H}(\text{PO}_4)_3 \cdot 2.5\text{H}_2\text{O}$ after 28 weeks, both products capable of providing more P for plants than $\text{Ca}(\text{NH}_4)_2\text{P}_2\text{O}_7 \cdot \text{H}_2\text{O}$. When APP was added to the surface of the slightly acid soil, $\text{NH}_4\text{H}_2\text{PO}_4$ and $(\text{NH}_4)_2\text{H}_2\text{P}_2\text{O}_7$ were found at 16 weeks. Both of these were considered capable of providing sufficient P for plants. At the 28-week sampling period, $\text{Ca}_4\text{H}(\text{PO}_4)_3 \cdot 2.5\text{H}_2\text{O}$ was present. This product was also considered capable of providing enough P for proper plant growth. The addition of AOP to the surface of the slightly acid soil produced $\text{MgHPO}_4 \cdot 3\text{H}_2\text{O}$ at 16 weeks and $\text{MgHPO}_4 \cdot 7\text{H}_2\text{O}$ at 28 weeks, both capable of providing sufficient P for plants. Subbarao and Ellis concluded that the only situation where a problem in limited availability of P might arise is when APP is added to a calcareous soil.

Other reaction product studies have been reported. When OP as $\text{Ca}(\text{H}_2\text{PO}_4)_2 \cdot \text{H}_2\text{O}$ and $\text{NH}_4\text{H}_2\text{PO}_4$ was added to a slightly acid soil or an alkaline soil, the product formed was $\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$, which results in P being available for plants (Bell and Black, 1970). In another study, ammonium tripolyphosphate readily transformed to slightly soluble calcium and magnesium ammonium tripolyphos-

phates which slowly hydrolyzed to their pyrophosphate salts at all pH levels (Philen and Lehr, 1967).

Effects of P sources on the availability and subsequent uptake of zinc into the plant have been studied. In one study, APP produced greater yields of corn silage than MAP when no zinc was applied; but with zinc applications, MAP produced higher yields (Terman and Engelstad, 1966). These results suggest a P carrier-zinc interaction.

Another researcher stated that no apparent significant effects on zinc uptake could be attributed to the carriers MAP, APP, or triple superphosphate (TSP) (Adriano, 1969). One exception was noted. On a non-calcareous soil in one year's data, MAP appeared slightly more beneficial to zinc uptake than did APP or TSP. This beneficial effect was noted at both early and late stages of plant development.

When zinc was incorporated into P fertilizers, greater increases in zinc uptake by pea beans was observed (Ellis, 1965). This phenomenon was noted with ZnO incorporated into APP rather than into AOP. In contrast, the zinc content of sudangrass (Sorghum vulgare sudanense) forages was noted to increase when zinc was incorporated into either granular APP or MAP (Allen and Terman, 1966).

In a study of the effects of additions of APP, MAP, and TSP on soil pH, Terman and Engelstad (1966) reported that APP decreased soil pH more than the other two materials. This depression in soil pH was related to a higher zinc uptake and subsequently higher yields of corn. An earlier study showed that soil pH is lowered only in the immediate vicinity of a superphosphate granule, where it can drop to as low as 1.5 (Viets, Boawn, and Crawford, 1957). Such acidity could enhance the solubility of zinc. It could also be detrimental to root development and so offer no advantage for increased nutrient uptake.

Looking at the solubilities of some reaction products of ZnSO_4 with

phosphorus carriers, Mortvedt and Giordano (1967) reported that the reaction product of MAP and ZnSO_4 would be ZnNH_4PO_4 . The solubility of this compound would tend to decrease with an increase in pH. They also indicated that the reaction product between ZnSO_4 and TAPP would be $\text{Zn}_3(\text{NH}_4)_2(\text{P}_2\text{O}_7)_2 \cdot 2\text{H}_2\text{O}$ at a pH less than 6.0. Above pH 6.0, the product would be $\text{Zn}(\text{NH}_4)_2\text{P}_2\text{O}_7 \cdot \text{H}_2\text{O}$.

In a study of zinc-phosphorus interactions in corn, it was found that each higher rate of zinc application usually increased zinc content of the plant when APP was used as a P carrier (Ganiron, Adriano, Paulsen, and Murphy, 1969). When MAP was used, only the highest level of zinc application increased zinc uptake. This suggests a favorable association between APP and zinc leading to more zinc uptake.

Zinc response on corn in the greenhouse was studied using a fine sandy loam soil of pH 7.1 (Terman and Allen, 1964). They observed that without applied zinc, dicalcium phosphate (DCP) and TSP induced severe zinc deficiency and depressed forage yields much more than APP and MAP. Lower soil pH also resulted with APP and MAP. With the application of 4 ppm zinc, the percent of zinc in the forage with the four P carriers was (highest to lowest): APP, MAP, CSP, and DCP.

Another study indicated that when ZnO was incorporated into AOP, the zinc was less water soluble than when the same quantity of ZnO was incorporated into APP (Lessman and Ellis, 1965). Zinc content of the pea beans at early growth stages was found to be related to the amount of water soluble zinc in the fertilizer mixture. The yield and zinc uptake data from this experiment indicated that when pea beans are grown on calcareous soils, APP is a more effective zinc carrier than AOP.

The main emphasis of these reports indicates that there may be advantages in terms of increasing zinc uptake into the plant by using PPP materials. The advantages with PPP may depend on soil pH or other factors, but they most likely are related to the ability of PPP to sequester zinc in solution.

METHODS AND MATERIALS

Field Experiments

Several irrigated field studies were initiated in 1974 and 1975 to evaluate ammonium orthophosphate and polyphosphate fertilizers. Variables studied were rate of P fertilization, type of P fertilizer, and zinc application. Grain yield and plant tissue composition (P and Zn) at two sampling dates were chosen as factors indicating the influence of each variable. Crops used were corn, soybeans, and grain sorghum (Sorghum bicolor).

Two general types of studies were used. One compared the influence of APP and AOP at different rates of application, with and without zinc (Tables 1, 2, 3, and 4); the other compared several types of P materials--APP, APP plus ethylenediamine tetracetate (EDTA), AOP, urea ammonium polyphosphate (UAPP), potassium polyphosphate (KPP), and sodium tripolyphosphate (NaTPP)--all at varying P rates. Treatments for these studies are described in Tables 5 and 6 along with analyses of the P materials used. With this later type of study, zinc was applied at a constant rate across all P variables.

The study comparing APP and AOP on corn at the Tribune Branch Experiment Station in Greeley County was conducted for two years, 1974-1975. Soil samples by plot were taken (0-15 cm) before application of 1975 fertilizer materials. Only 1975 data are available for the P materials comparison (Table 5) on corn at this same location. 1974 was the only year for the APP-AOP and P material studies on the Irsik farm in Finney County, and 1975 was the only year for these studies on the Holcomb Irrigation Field in Finney County. All these involved grain sorghum as the crop. Data from 1974 with soybeans on the Compton farm in Pawnee County are available with the APP-AOP study. 1975 was a residual year for this study.

Soil test data and general plot site information for all locations are given in Table 7. Available P was determined by the Bray P-1 method and

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Table 1. Fertilizer treatments for APP-AOP comparison on irrigated grain sorghum, Irsik farm, east and west locations (Finney County, 1974).

Fertilizer Rates		P Carrier
kg P/ha	kg Zn/ha	
0	0	---
20	0	APP
40	0	APP
60	0	APP
20	0	AOP
40	0	AOP
60	0	AOP
20	4.5	APP
40	4.5	APP
60	4.5	APP
20	4.5	AOP
40	4.5	AOP
60	4.5	AOP

All treatments included 224 kg N/ha as urea ammonium nitrate 28% N solution and 22.5 kg S/ha as ammonium thiosulfate. Zinc was applied as ZnO, APP as 11-16-0, and AOP as 18-20-0.

Table 2. Fertilizer treatments for APP-AOP comparison on irrigated corn, Tribune Branch Experiment Station (Greeley County, 1974-1975).

Fertilizer Rates		P Carrier
kg P/ha	kg Zn/ha	
0	0	---
20	0	APP
40	0	APP
20	0	AOP
40	0	AOP
0	9	---
20	9	APP
40	9	APP
20	9	AOP
40	9	AOP

In 1974, Zn was applied as ZnSO_4 , APP as 15-27-0, and AOP as 18-20-0. Total N application was 224 kg N/ha, 190 kg N/ha as NH_3 and 34 kg N/ha as NH_4NO_3 . In 1975, Zn was applied as Zn-NH_3 , APP as 11-16-0, and AOP as 18-20-0. Total N application was 224 kg N/ha as urea ammonium nitrate 28% N solution.

Table 3. Fertilizer treatments for APP-AOP comparison on irrigated soybeans, Compton farm (Pawnee County, 1974).

Fertilizer Rates		P Carrier
kg P/ha	kg Zn/ha	
0	0	---
20	0	APP
40	0	APP
60	0	APP
20	0	AOP
40	0	AOP
60	0	AOP
20	9	APP
40	9	APP
60	9	APP
20	9	AOP
40	9	AOP
60	9	AOP

All treatments included 168 kg N/ha as urea ammonium nitrate 28% N solution and 22.5 kg S/ha as ammonium thiosulfate. Zinc was applied as Zn-NH₃, APP as 11-16-0, and AOP as 18-20-0.

Table 4. Fertilizer treatments for APP-AOP comparison on irrigated grain sorghum, Holcomb Irrigation Field (Finney County, 1975).

Fertilizer Rates		P Carrier
kg P/ha	kg Zn/ha	
0	0	---
20	0	APP
40	0	APP
60	0	APP
20	0	AOP
40	0	AOP
60	0	AOP
20	4.5	APP
40	4.5	APP
60	4.5	APP
20	4.5	AOP
40	4.5	AOP
60	4.5	AOP
0	4.5	---

All treatments received 224 kg N/ha as urea ammonium nitrate 28% N solution and 22.5 kg S/ha as ammonium thiosulfate. APP was applied as 11-16-0, AOP as 18-20-0, and Zn as ZnO.

Table 5. Fertilizer treatments for P material comparison on irrigated corn, Tribune Branch Experiment Station (Greeley County, 1975) and on irrigated grain sorghum, Holcomb Irrigation Field (Finney County, 1975).

Fertilizer Rates		
kg P/ha	P Carrier	P form
0	-----	---
20	11-16-0	APP
40	11-16-0	APP
20	21-18-0	UAPP
40	21-18-0	UAPP
20	18-20-0	AOP
40	18-20-0	AOP
20	0-22-33	KPP
40	0-22-33	KPP
20	0-26-0	NaTPP
40	0-26-0	NaTPP
20	11-16-0+EDTA	APP
40	11-16-0+EDTA	APP

All treatments received 224 kg N/ha as urea ammonium nitrate 28% N solution and 4.5 kg Zn/ha as Zn-NH₃.

Table 6. Fertilizer treatments for P material comparison on irrigated grain sorghum, Irsik farm, east and west locations (Finney County, 1974).

kg P/ha	Fertilizer Rates	
	P Carrier	P form
0	-----	---
20	11-16-0	APP
40	11-16-0	APP
20	21-18-0	UAPP
40	21-18-0	UAPP
20	18-20-0	AOP
40	18-20-0	AOP
20	0-22-33	KPP
40	0-22-33	KPP

All treatments received 224 kg N/ha as urea ammonium nitrate 28% N solution, 22.5 kg S/ha as ammonium thiosulfate, and 3.4 kg Zn/ha as Dow Zn EDTA.

Table 7. Experimental Site Data for Field Studies

Location	County	Available P (kg/ha)	pH	Exchangeable K (kg/ha)	OM %	DTPA		Soil Name	Soil Type
						Extractable	Zn (ppm)		
Tribune	Greeley							Aridic Haplustolls	Ulysses sil
APP-AOP		20	7.7	2316	1.5		0.72		
P material		21	7.8	1049	--- ^{a/}		0.59		
Irsik (West)	Finney	8	7.9	1577	2.4		0.60	Typic Argiustolls	Harney sil
Irsik (East)	Finney	24	7.2	2439	1.9		1.15	Typic Argiustolls	Harney sil
Holcomb	Finney							Aridic Haplustolls- Argiustolls	Ulysses-Richfield silted
APP-AOP		8	8.0	594	---		2.37		
P material		11	7.9	683	---		0.57		
Compton	Pawnee	29	7.2	560	0.6		0.90	Udic Argiustolls	Naron ls

Depth on all samples was 15 cm.

a/ Samples were unavailable for OM analysis.

available Zn by the DTPA extraction procedure. Other determinations were according to the Kansas State University soil testing lab procedures.

All treatments were arranged in a randomized complete block design. Plots were 4-5 rows wide (3-3.8 meters) and 6.1-9.1 meters in length depending on location and available space.

Fertilizer materials on all studies were mechanically applied preplant and incorporated by disking. Planting was carried out by either the field personnel or cooperating farmer. Herbicides and pesticides were applied as necessary. Once the plants had grown to a height of several inches, strips were hoed out at the end of each plot to mark the boundaries.

Tissue samples were taken twice during the growing season. The first sampling was at approximately the 8-leaf stage for the corn and sorghum and early bloom for the soybeans. A composite of the last or youngest fully extended leaf or trifoliolate randomly selected from the plants of the center two rows were collected. The second sampling occurred at either the boot stage for sorghum, the tassel stage for corn, or the early pod stage for soybeans. The last or youngest fully extended leaf or trifoliolate was taken for the sorghum and soybeans; and the leaf opposite and below the forming ear was taken on the corn. A composite sample was used as described earlier.

The center two rows of each soybean plot were harvested with a plot combine. Grain yields were converted to kg/ha at 12.5% moisture. One row from the center of the plot was hand harvested on the corn and sorghum. This material was either threshed or shelled, and the grain yields were reported as kg/ha at 12.5% moisture.

APP fertilizers were applied as either liquid 11-16-0 (%N-%P-%K), 11-16-0 plus EDTA, or solid 15-27-0. AOP was always applied as solid 18-20-0. UAPP was applied as solid 21-18-0, and KPP as solid 0-22-33. NaTPP was a solid 0-26-0 material, but it was applied as a solution after dissolving in water. No other form of a TPP fertilizer was available other than

NaTPP. Zinc was applied in several forms, Zn EDTA and Zn-NH₃ (liquids) and ZnSO₄ and ZnO (solids), depending on the year and location. The Zn-NH₃ material contained 10% each of zinc and nitrogen. Sulfur was always applied as ammonium thiosulfate and nitrogen was applied as NH₃, NH₄NO₃, or urea ammonium nitrate (UAN) 28% nitrogen solution.

Plant leaf material taken for analysis was washed in distilled-deionized water, dried in a forced air dryer at 50 C for 72 hours, and ground in a Wiley mill with stainless steel knives and 2 mm stainless steel screen. The ground material was then stored in plastic containers for later analysis.

Preparation for P analysis in 1974 was by a sulfuric acid digestion. A 0.5 g sample of tissue and 10 ml of concentrated sulfuric acid were placed in a 100 ml volumetric flask and heated on a hot plate until digestion was complete. The resulting solution was diluted with distilled-deionized water to 100 ml. Phosphorus was determined according to a modification of the vanadate-molybdate yellow color method of Jackson (1965). Twenty-five ml of the vanadate-molybdate solution¹ was added to a 5-ml aliquot of the digestion solution. The color was allowed to develop for 30 minutes and absorbance was read on a Spectronic 88 spectrophotometer at a wavelength of 390 nm.

Digestion for Zn analysis in 1974 and Zn and P analysis in 1975 was accomplished by dry ashing one-g samples of plant material in 20-ml beakers in a muffle furnace. The temperature was maintained at 200 C for one hour and 550 C for 3 hours. Beakers were allowed to cool. After 10 ml of 0.1N HCl was added to the residue in the beakers, the solution was warmed on a

¹ Vanadate-molybdate solution was prepared by dissolving 195 g of (NH₄)₆Mo₇O₂₄ · H₂O in 1 L of H₂O and dissolving 5.05 g of NH₄VO₃ in 1 L of boiling H₂O. Both solutions were transferred to a carboy and diluted to 18 L with distilled-deionized H₂O.

hot plate, filtered through Whatman 41 ashless filter paper into 50-ml volumetric flasks, and diluted to 50-ml volume with 0.1N HCl. Zinc in this solution was read on a Perkin-Elmer 303 atomic absorption spectrophotometer. P concentrations in this solution in 1975 were determined according to the modification of the vanadate-molybdate method of Jackson (1965) used for the sulfuric acid digestion procedure in 1974. A 1-ml aliquot was used, and the vanadate-molybdate solution was acidified with nitric acid to get proper color development.

Statistical analysis of the data was accomplished using an analysis of variance procedure on the Kansas State University computer.

Growth Chamber Experiments

Growth chamber evaluations of APP and AOP effectiveness at different rates of application with and without zinc were conducted. Several soils were utilized, three from the same locations where field studies were in progress--Tribune, Irisk farm (west location), and Irsik farm (east location). One soil from Jewell County (Burr Oak location) and two soils from the Mississippi Delta area of northeastern Arkansas and western Tennessee (Sisk and Cotter locations) were also included. Soil test data and general information for these soils are given in Table 8. Treatments for the studies are listed in Tables 9 and 10. APP was applied as 15-27-0, AOP as 18-20-0, K and S as K_2SO_4 , Zn as ZnO, and the remainder of N as urea.

The soil was air dried and screened to remove large particles. Fertilizer material which had been previously weighed into coin envelopes was mixed with the soil using a mechanical-revolving mixer. Each plastic pot contained 750 g of soil. Three replicates for each treatment with each soil were included.

The growth chamber was set to maintain 27 C day and 20 C night temperatures. Day length was 16 hours. Lighting was provided by fluorescent and

Table 8. Experimental Soil Data for Growth Chamber Studies

Location	County	Available P (kg/ha)	pH	Exchangeable K (kg/ha)	OM %	DTPA		Soil Name	Soil Type
						Extractable Zn (ppm)			
Tribune	Greeley	20	7.7	2316	1.5	0.72		Ardic Haplustolls	Ulysses sil
Irsik (West)	Finney	8	7.9	1577	2.4	0.60		Typic Argiustolls	Harney sil
Irsik (East)	Finney	24	7.2	2439	1.9	1.15		Typic Argiustolls	Harney sil
Burr Oak	Jewell	7	8.0	605	2.2	0.49		Typic Haplustolls	Wakeen scl
Sisk	-----	41	6.6	247	1.4	1.42		- - - - -	- - - - -
Cotter	-----	40	6.2	164	1.2	1.96		- - - - -	- - - - -

Table 9. Fertilizer treatments for corn grown in the growth chamber with soils from Tribune (Greeley County) and Irsik farm, east and west locations (Finney County).

Fertilizer Rates		P Carrier
ppm P	ppm Zn	
0	0	---
20	0	AOP
40	0	AOP
80	0	AOP
20	0	APP
40	0	APP
80	0	APP
20	8	AOP
40	8	AOP
80	8	AOP
20	8	APP
40	8	APP
80	8	APP

All treatments received 150 ppm N as urea, 100 ppm K and 43 ppm S as K_2SO_4 . AOP was supplied as 18-20-0, APP as 15-27-0, and Zn as ZnO.

Table 10. Fertilizer treatments for corn grown in the growth chamber with Mississippi Delta (Sisk and Cotter locations) and Jewell County (Burr Oak location) soils.

Fertilizer Rates		P Carrier
ppm P	ppm Zn	
0	0	---
20	0	AOP
40	0	AOP
80	0	AOP
20	0	APP
40	0	APP
80	0	APP
0	8	---
20	8	AOP
40	8	AOP
80	8	AOP
20	8	APP
40	8	APP
80	8	APP

All treatments received 150 ppm N as urea, 100 ppm K and 43 ppm S as K_2SO_4 . APP was applied as 15-27-0, AOP as 18-20-0, and Zn as ZnO.

incandescent bulbs. Distilled-deionized water was applied daily as needed.

Two separate corn crops were grown on the soils from Tribune, Irsik (west location), and Irsik (east location). Corn was planted again after the first crop had been harvested and the study was carried out as before. Additional N (150 ppm) as urea was added between crops. A single corn crop was harvested from the other soils.

Eight grains of DeKalb XL-390 corn were planted per pot. Plants were thinned to 3 per pot one week after emergence. Approximately two weeks after emergence of the second crop on the Tribune and Irsik soils and after emergence of the first crop on the Burr Oak soil, 5 ppm Fe as Geigy Sequestrene 330 iron chelate was applied to the soil surface as a solution.

Plants were allowed to grow until 3 weeks after emergence when they were harvested by clipping all plants 2.5 cm above the soil surface. Soil samples were analyzed for available P and Zn after the harvest of each crop. Procedures for analysis were the same as for the field studies. Plants harvested were weighed wet, dried in a forced air dryer at 50 C for 72 hours, and weighed dry to determine fresh and dry weight yields. The plant material was then ground in a micro-Wiley mill with stainless steel knives and screen and placed in plastic containers for later analysis.

Digestion of the material for P and Zn analysis was by the dry ashing procedure as described for the field studies. Chemical analysis procedures for P and Zn determinations and statistical analysis of the data were also the same as for the field studies.

RESULTS AND DISCUSSION

Field Studies

Data presented in Figures 1-14 are calculated from actual field data. Mean values presented in these figures are recorded in Appendix Tables I-IX. Data for individual treatments and mean values not presented in figures are included in these appendix tables along with all LSD values calculated at the 5% significance level.

No sorghum grain yield data are available for the APP-AOP and P material comparison studies on the Irsik farm in Finney County for 1974. All plots were inadvertently harvested by custom combine crews.

APP-AOP Comparisons

Corn grain yields at the Tribune location (soil pH 7.7) were unusually low in 1974. This can be attributed to extremely hot and dry conditions during the summer and a hail storm that swept the area on August 10. In spite of low yields, treatment variables significantly influenced grain production (Appendix Table I). A significant response was noted to P application over the control and to 40 kg P/ha over 20 kg P/ha (Fig. 1 and Appendix Table I).

In 1975, the same responses to added P and to 40 versus 20 kg P/ha were again observed (Fig. 1 and Appendix Table II). The individual treatment that gave the highest yield both years was 40 kg P/ha as APP in combination with 9 kg Zn/ha (Appendix Tables I and II). However, the mean values indicated that AOP resulted in a slightly higher yield than APP in 1974 and 1975; but these advantages were not statistically significant either year (Fig. 1 and Appendix Tables I and II). The slight superiority of AOP over APP might be expected because of the high soil pH (7.7) and some possible restrictions in PPP hydrolysis and availability through calcium precipitation reactions. Such reactions were demonstrated by Subbarao (1975).

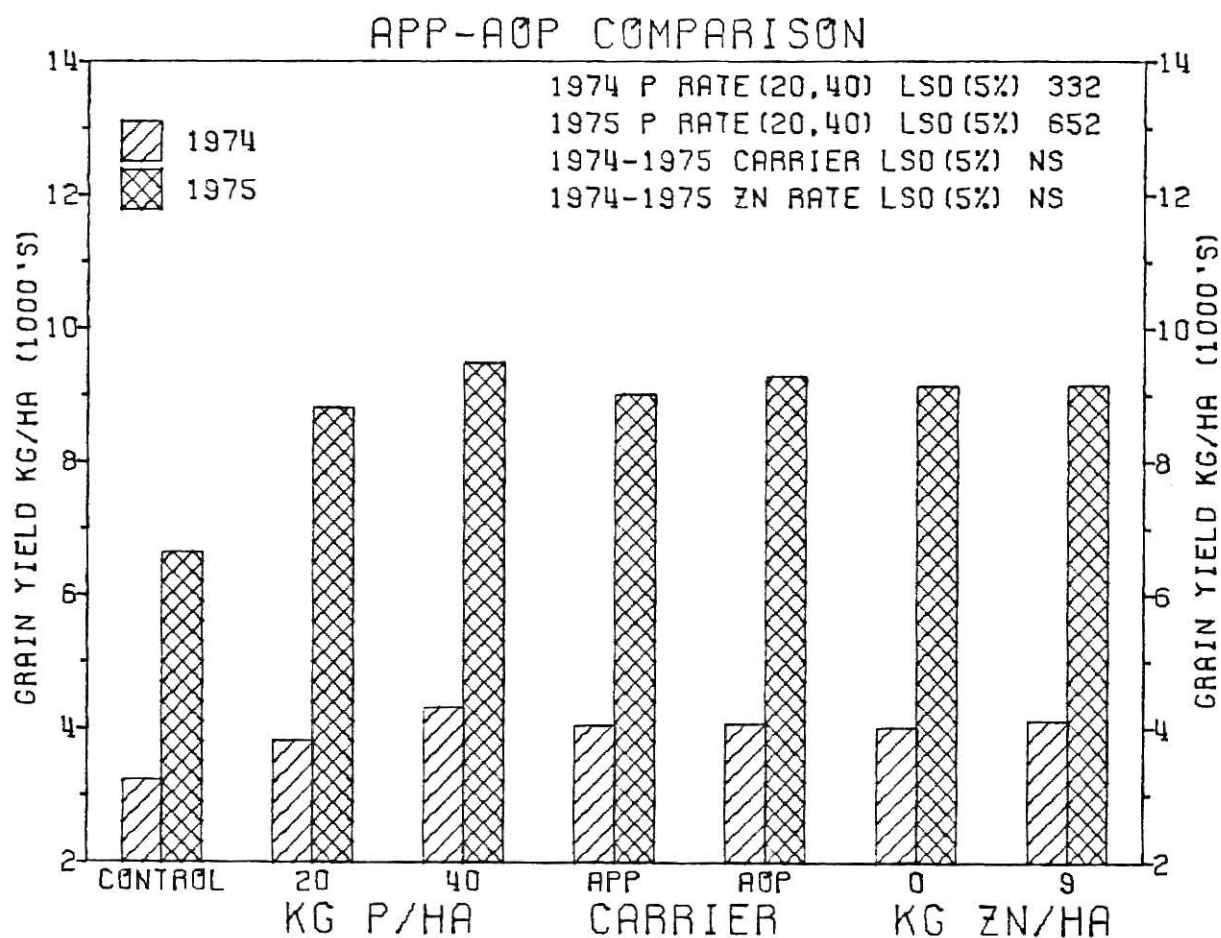


Fig. 1. Effects of P rate, P carrier, and Zn rate on grain yield of irrigated corn (Tribune, 1974-1975).

A significant increase in tissue P concentrations for 1974 was noted for the treatment variables containing P over the control for both sampling dates (Fig. 2 and Appendix Table I). No differences were recorded between APP and AOP effects on %P (Fig. 2). The only variable which influenced Zn content of the tissue was the application of Zn to the soil (Fig. 2). This was true for both sampling dates and occurred in 1975 also.

A response to added P was also observed in 1975 in terms of increased %P in the leaf tissue at both sampling dates. The two carriers, APP and AOP, had equal effects on %P in the leaf tissue. Identical effects were noted in 1974 (Fig. 2 and Appendix Table II).

Only one significant interaction occurred in both years at the Tribune site. This was a P carrier-P rate influence on Zn concentration in the leaf tissue at early sampling in 1974 (Fig. 3). At 20 kg P/ha, AOP applications were associated with more Zn in the tissue than were APP treatments. At 40 kg P/ha, the opposite occurred. A possible explanation might be that at the higher P rate, a depression in Zn uptake was occurring with the use of AOP because of increased P absorption. APP on the other hand may have increased absorption of both P and Zn due to enhancement of Zn uptake by APP as reported by Lessman and Ellis (1965) and Terman and Allen (1964).

A small increase in available soil Zn was noted where APP was used versus AOP in soil samples taken at the Tribune location before the application of the 1975 treatments (Appendix Table I). Although this increase was not statistically significant, it is worth noting.

At the Holcomb Irrigation Field (soil pH 8.0) in 1975, significant treatment responses to added P was recorded in terms of higher grain sorghum yields (Appendix Table III). As at the Tribune location, AOP resulted in a very slight increase in yield over APP, but again the difference was not statistically significant. No other significant yield effects were noted (Fig. 4).

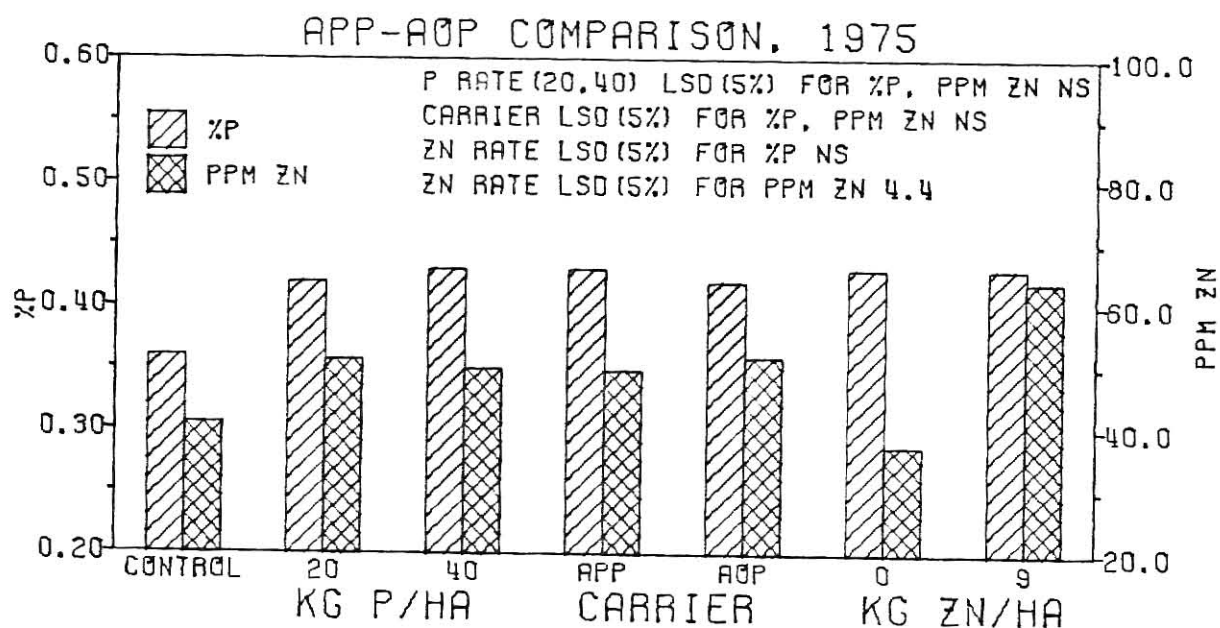
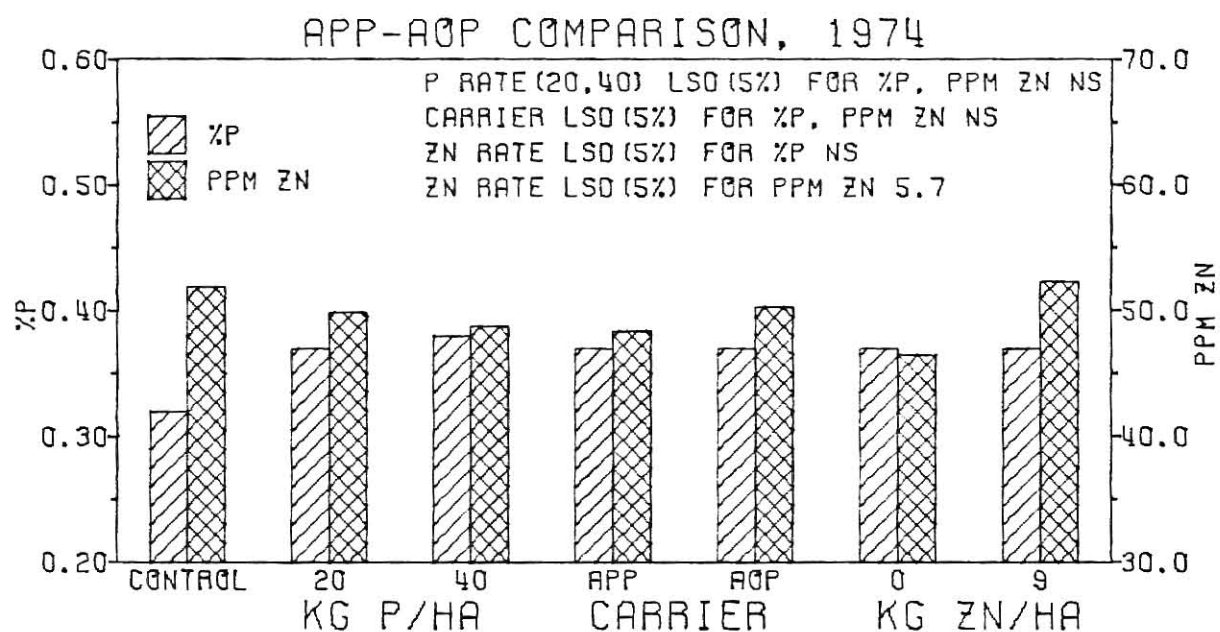


Fig. 2. Effects of P rate, P carrier, and Zn rate on irrigated corn leaf P and Zn concentrations at early sampling (Tribune).

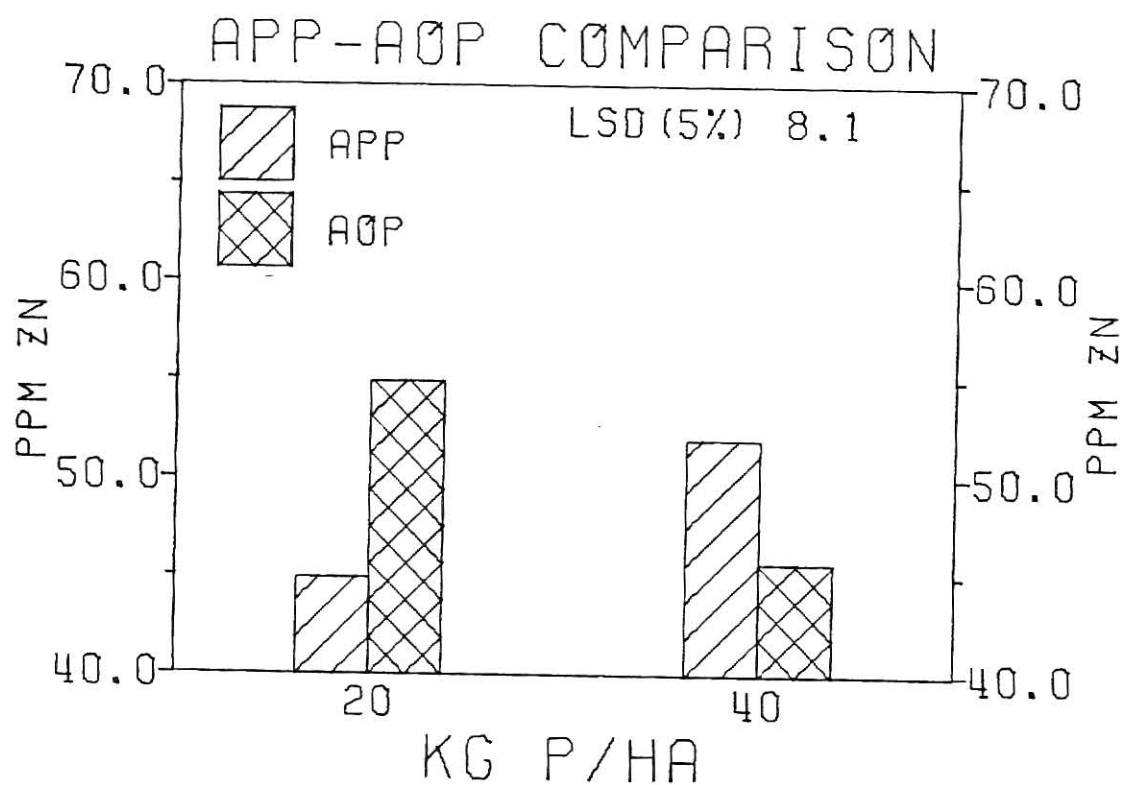


Fig. 3. Irrigated corn leaf Zn concentrations as affected by P carrier and P rate (early sampling, Tribune, 1974). Values are averaged across Zn rates.

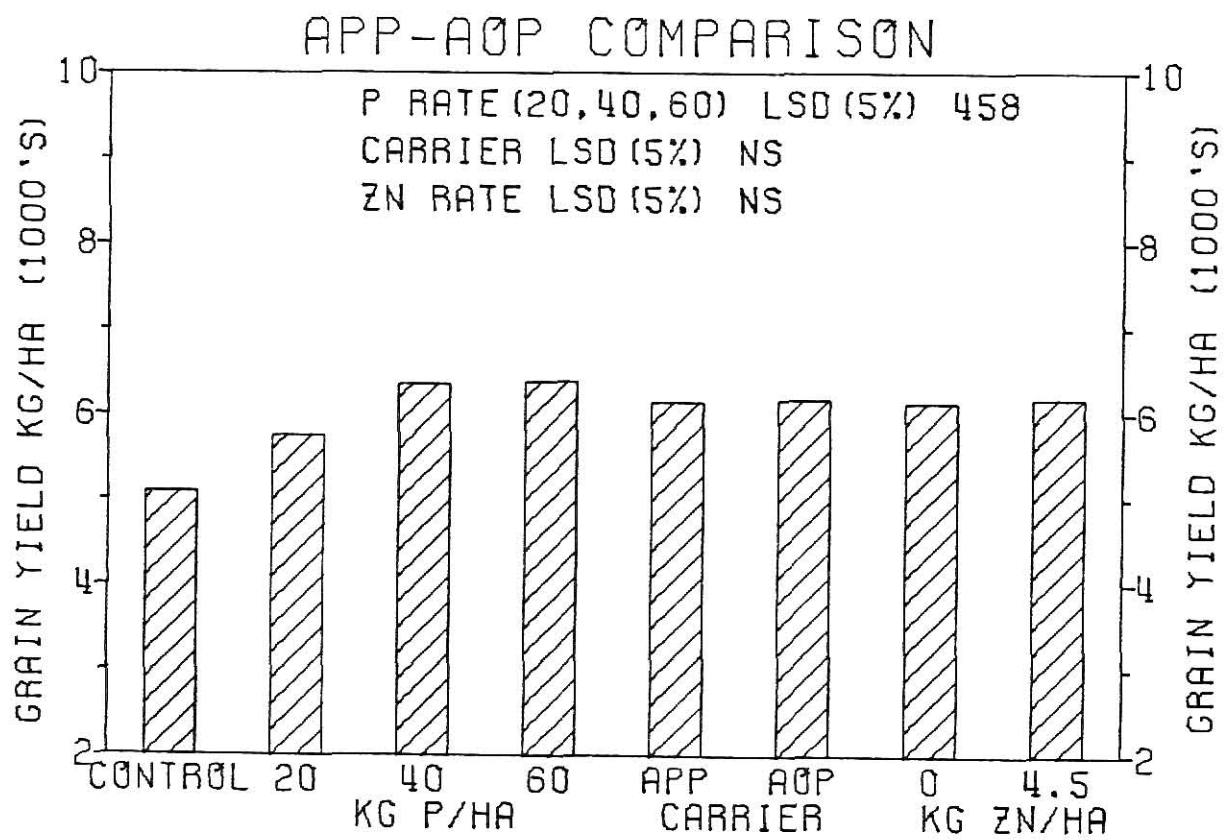


Fig. 4. Effects of P rate, P carrier, and Zn rate on grain yield of irrigated sorghum (Holcomb, 1975).

Leaf %P was significantly increased by additions of P to the soil at both sampling dates. APP increased leaf %P over AOP by 0.22% at the early sampling (Fig. 5). This difference was not significant at the 5% level but was significant at the 10% level. This occurrence was contrary to earlier results and is difficult to explain. However, three things should be pointed out: this increase in %P by APP is a very small increase, this increase was not reflected in yields, and this increase occurred at only the early sampling time.

In terms of Zn concentration in the plant, APP increased Zn by several ppm over AOP at both sampling dates even though this was not a significant increase (Fig. 5 and Appendix Table III). The ability of APP to increase Zn uptake has been observed by other researchers (Ganiron, Adriano, Paulsen, and Murphy, 1969) and (Lessman and Ellis, 1965).

The west location on the Irsik farm (soil pH 7.9) in 1974 showed the same increase in %P with APP over AOP that was observed at the Holcomb location (Fig. 6). This time the difference was significant at 5% at the second sampling date but not significant at the early sampling (Appendix Table IV). This also seems contrary to expected results in light of Subbarao's work because the soil pH is fairly high (7.9) and so restricted P availability could occur. Evidently, biological activity was high enough to offset the effect of a high pH so that hydrolysis occurred fast enough to offer a good supply of P to the plant. The organic matter content of this soil was 2.4% (Table 7), and so the biological activity should be high enough for an adequate rate of hydrolysis to occur. The relationship between biological activity and PPP hydrolysis has been cited by Sutton and Larsen (1964). No other significant mean effects for carriers were noted here or at the east location of the Irsik farm (Fig. 7 and Appendix Tables IV and V).

Similar interaction effects as reported in Fig. 3 were noted between P rate and P carrier influence on Zn content at the early sampling from the

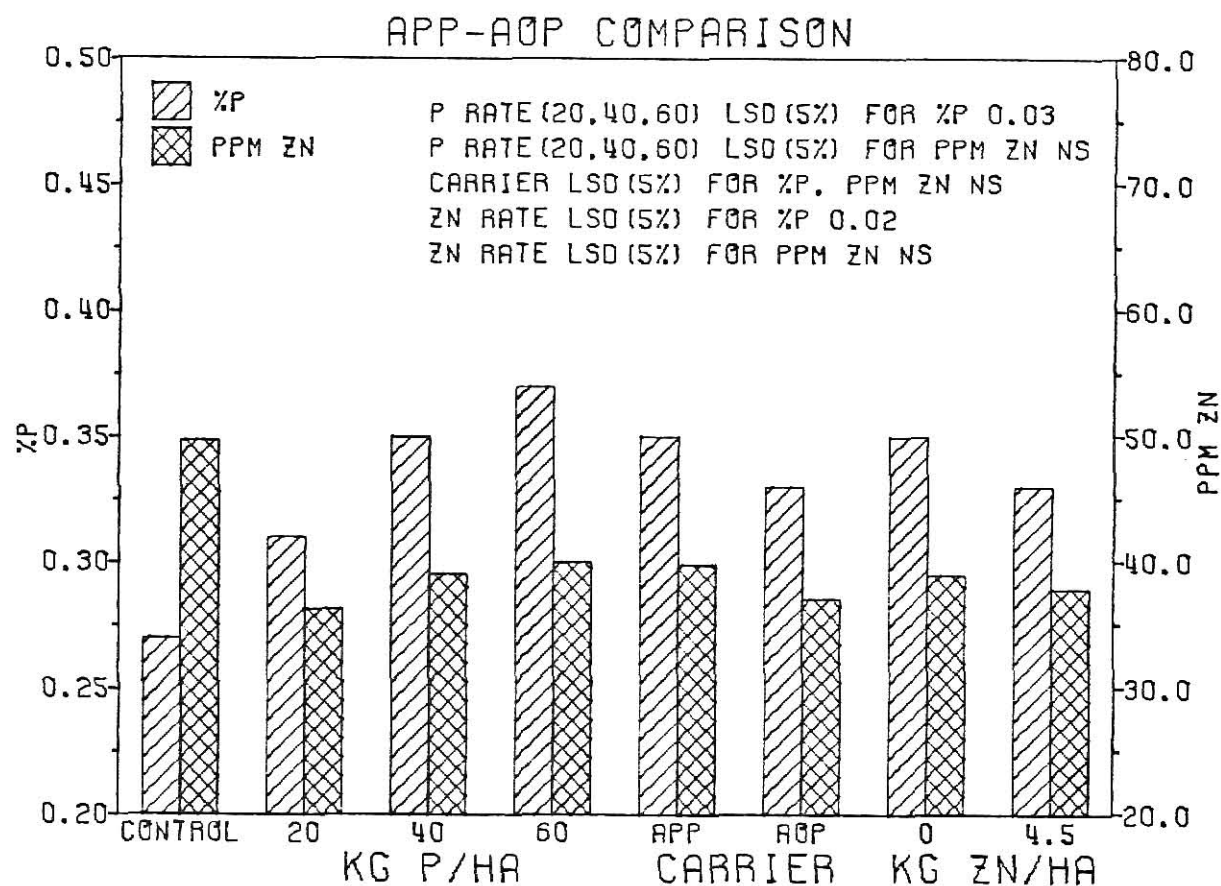


Fig. 5. Effects of P rate, P carrier, and Zn rate on irrigated sorghum leaf P and Zn concentrations at early sampling (Holcomb, 1975).

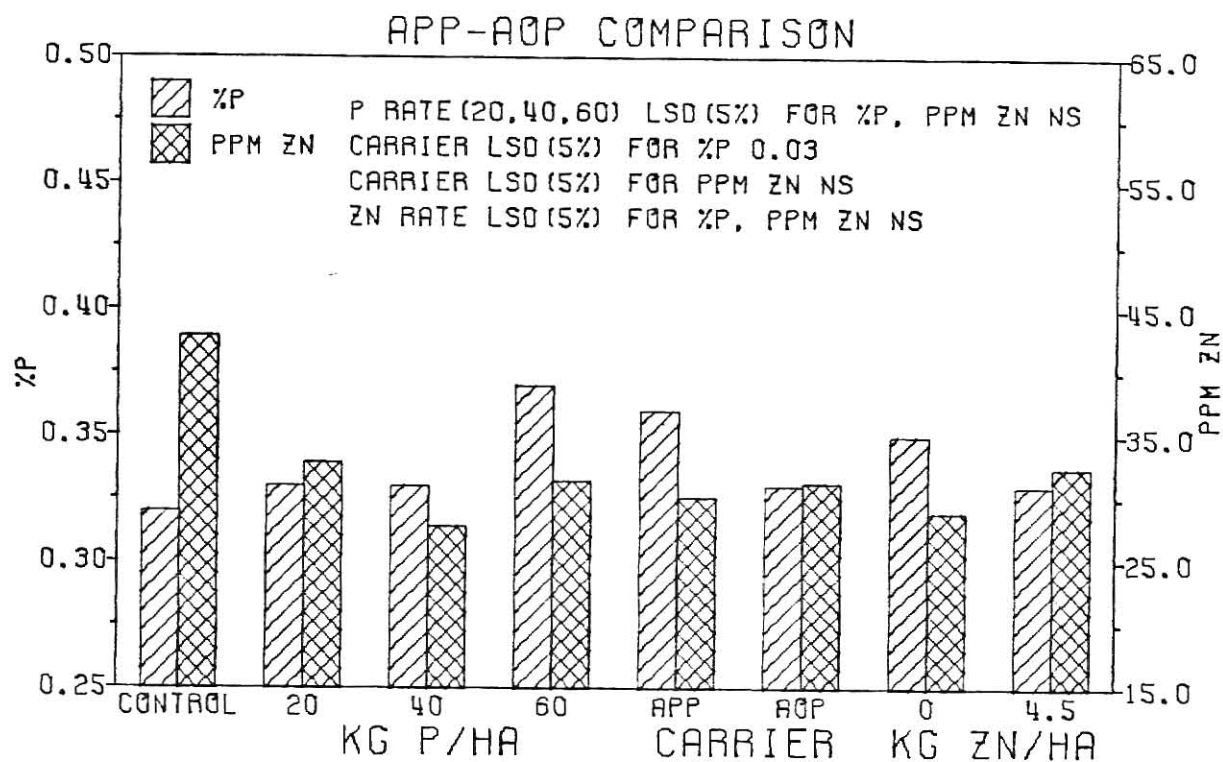


Fig. 6. Effects of P rate, P carrier, and Zn rate on irrigated sorghum leaf P and Zn concentrations at early sampling (Irsik farm, west location, 1974).

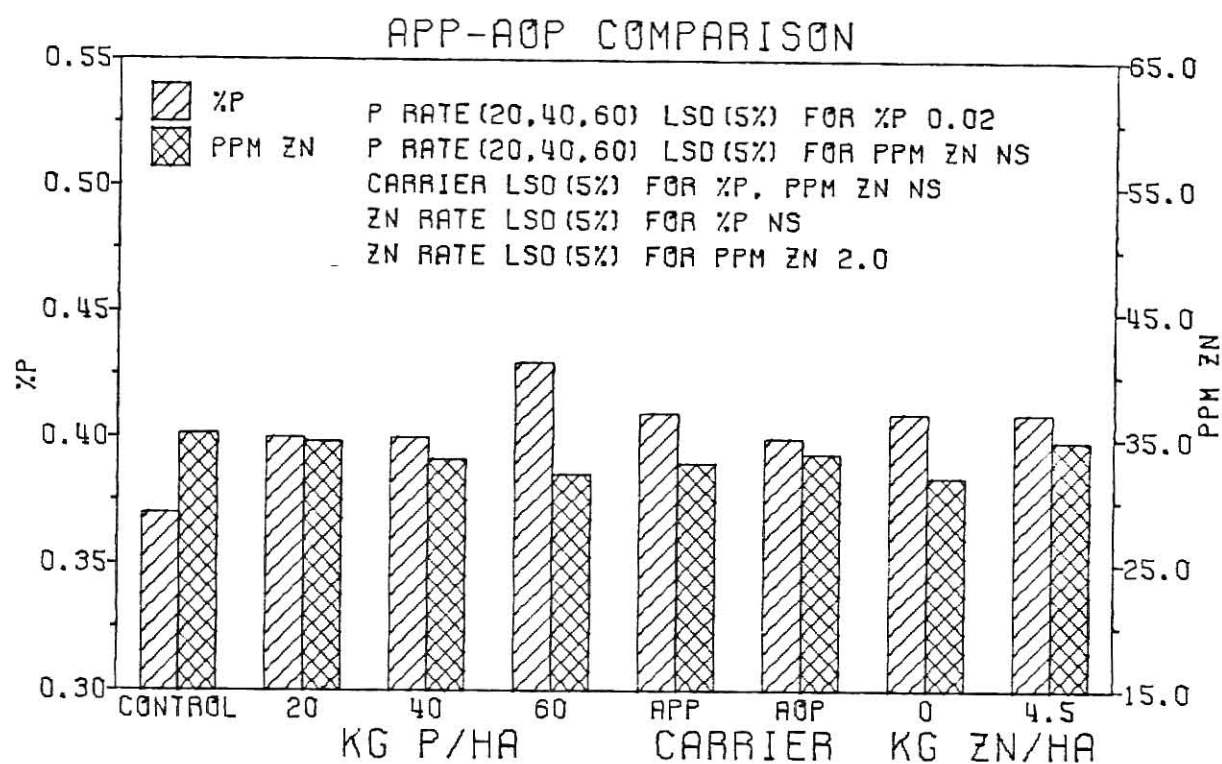


Fig. 7. Effects of P rate, P carrier, and Zn rate on irrigated sorghum leaf P and Zn concentrations at late sampling (Irsik farm, east location, 1974).

east location of the Irsik farm (Fig. 8). At the 40 kg P/ha rate, APP produced higher Zn uptake than AOP; but the trend was reversed at the 60 kg P/ha rate. The reason for this effect is unknown.

Comparison of APP and AOP as P sources for irrigated soybeans at the Compton farm in Pawnee County (soil pH 7.2) produced few significant differences in 1974 or 1975 (residual effects). APP and AOP were equal in effect on grain yield, %P, and ppm Zn in the plant tissue (Fig. 9-11 and Appendix Tables VI-VII). When the study was continued on a residual basis in 1975, a highly significant increase in Zn concentration in the trifoliate leaves as a result of Zn added in 1974 was observed (Fig. 11). These data indicate that it is not necessary to add Zn every year for soybeans if adequate amounts are used initially and if soil Zn levels are monitored by soil analysis. Phosphorus sources exerted no differential effects on P or Zn uptake.

P Material Comparisons

In this series of studies, six P carriers were examined (Tables 5-6). The studies were conducted at many of the same locations where the APP-AOP comparisons were located.

At the Tribune location, the only variable affecting corn grain yield was P rate (Fig. 12), with 40 kg P/ha significantly increasing yield over 20 kg P/ha. No carrier was superior to another even though KPP produced a yield of over 130 kg/ha more than NaTPP. The carriers were even closer in their effect on P concentration in the leaf tissue at both sampling dates (Fig. 12 and Appendix Table VIII).

A significant grain sorghum response to applied P was observed at the Holcomb Irrigation Field in 1975 (Fig. 13 and Appendix Table VIII). As was the case at Tribune, no significant differences were recorded among P carriers. A significant difference among carriers in leaf tissue P concentration was noted at the early sampling (Fig. 13). The carrier giving the highest %P

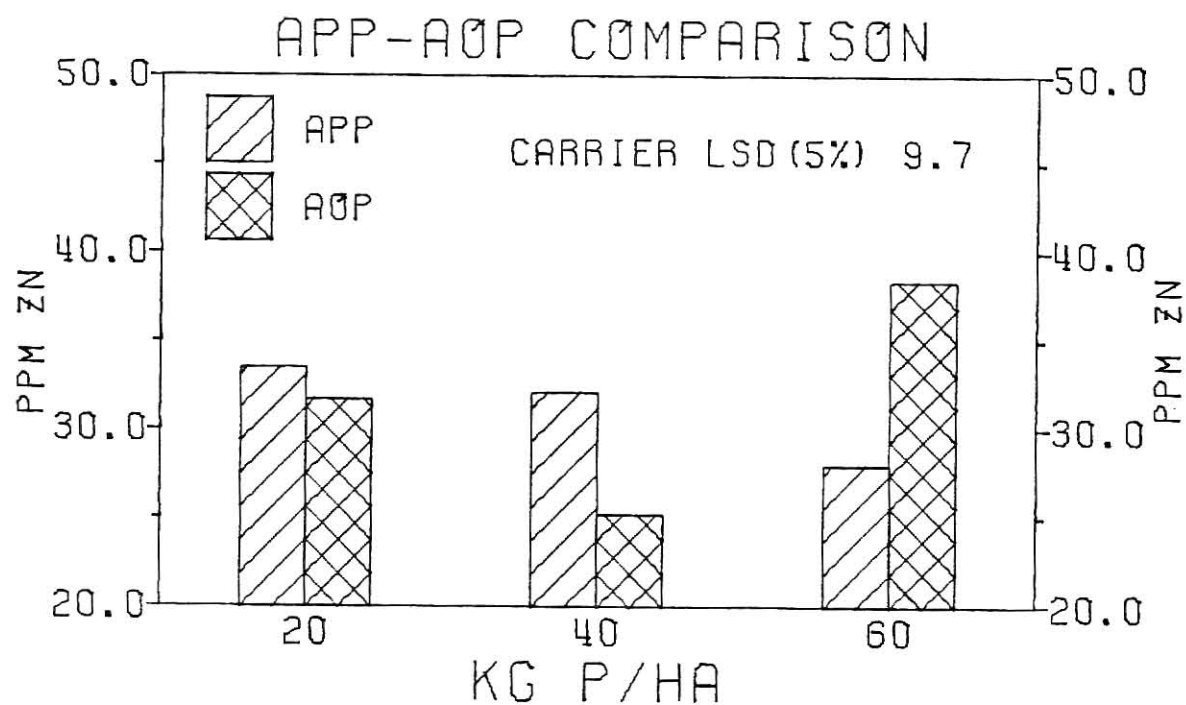


Fig. 8. Irrigated sorghum leaf concentration as affected by P carrier and P rate at early sampling (Irsik farm, east location, 1974). Values are averaged across Zn rates.

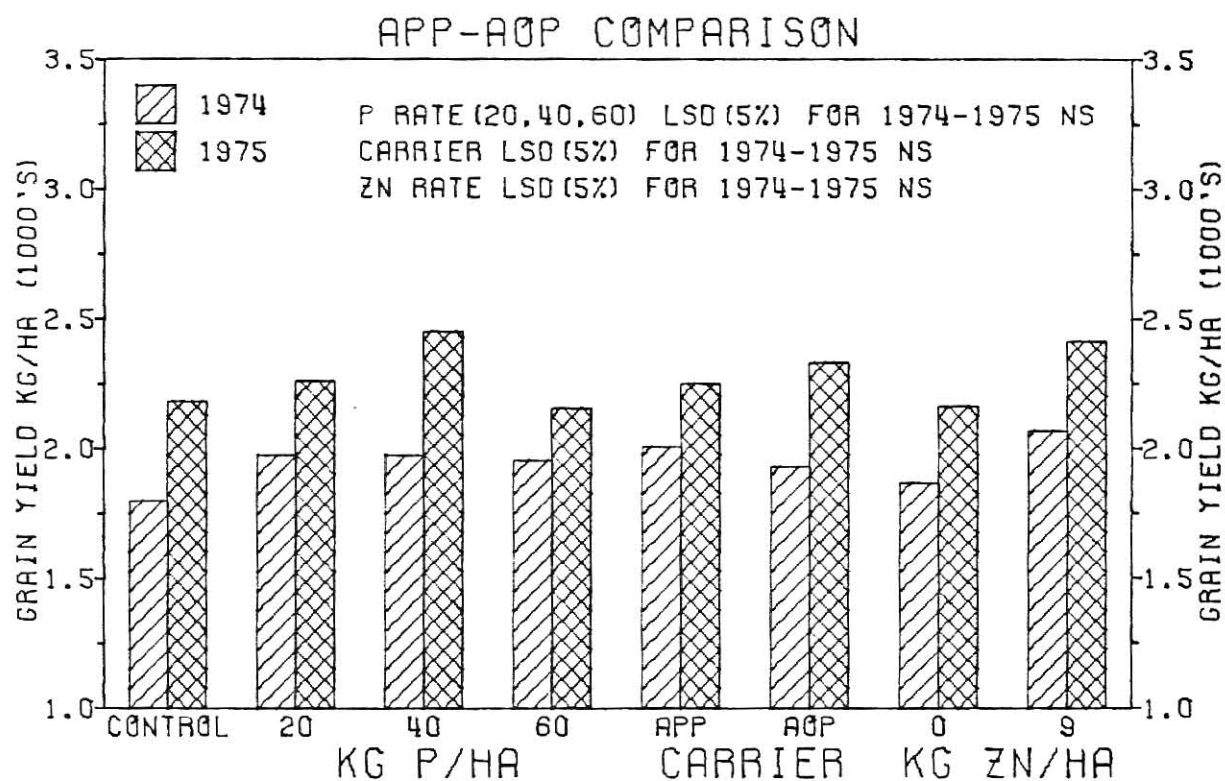


Fig. 9. Effects of P rate, P carrier, and Zn rate on irrigated soybean grain yield (Compton farm, 1974-1975).

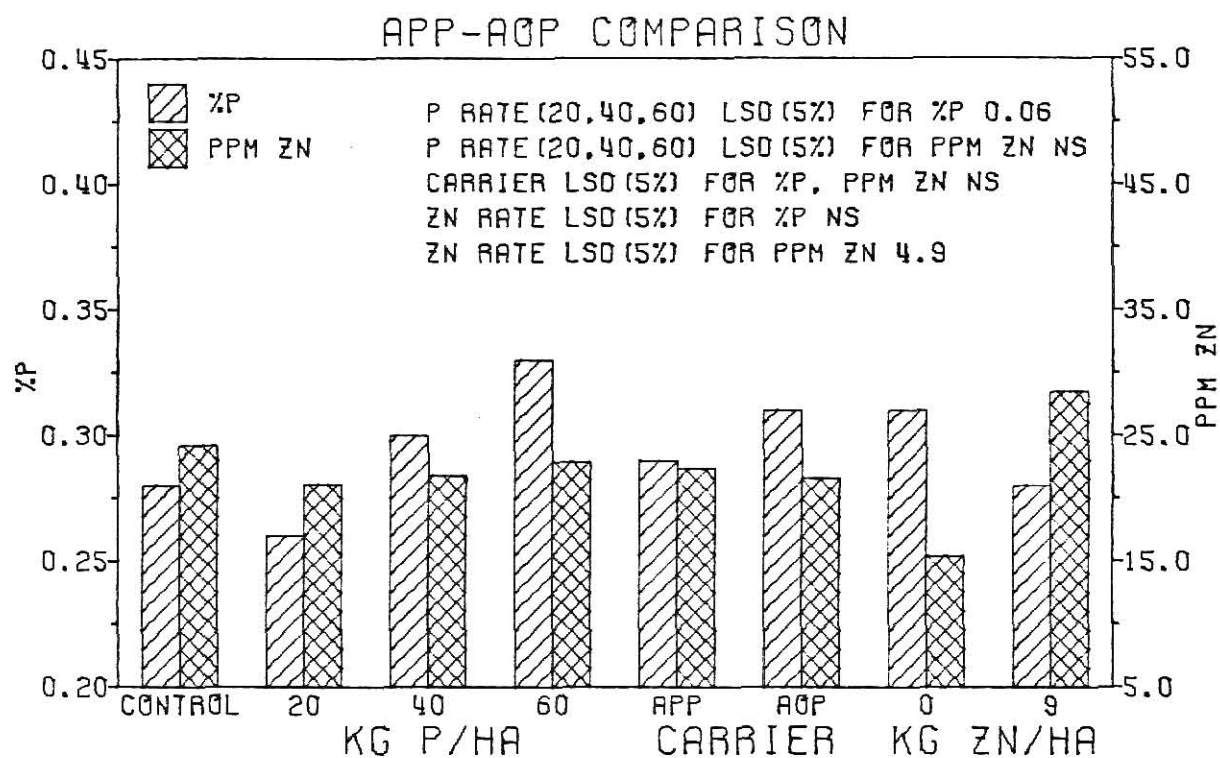


Fig. 10. Effects of P rate, P carrier, and Zn rate on irrigated soybean trifoliolate P and Zn concentrations at early bloom (Compton farm, 1974).

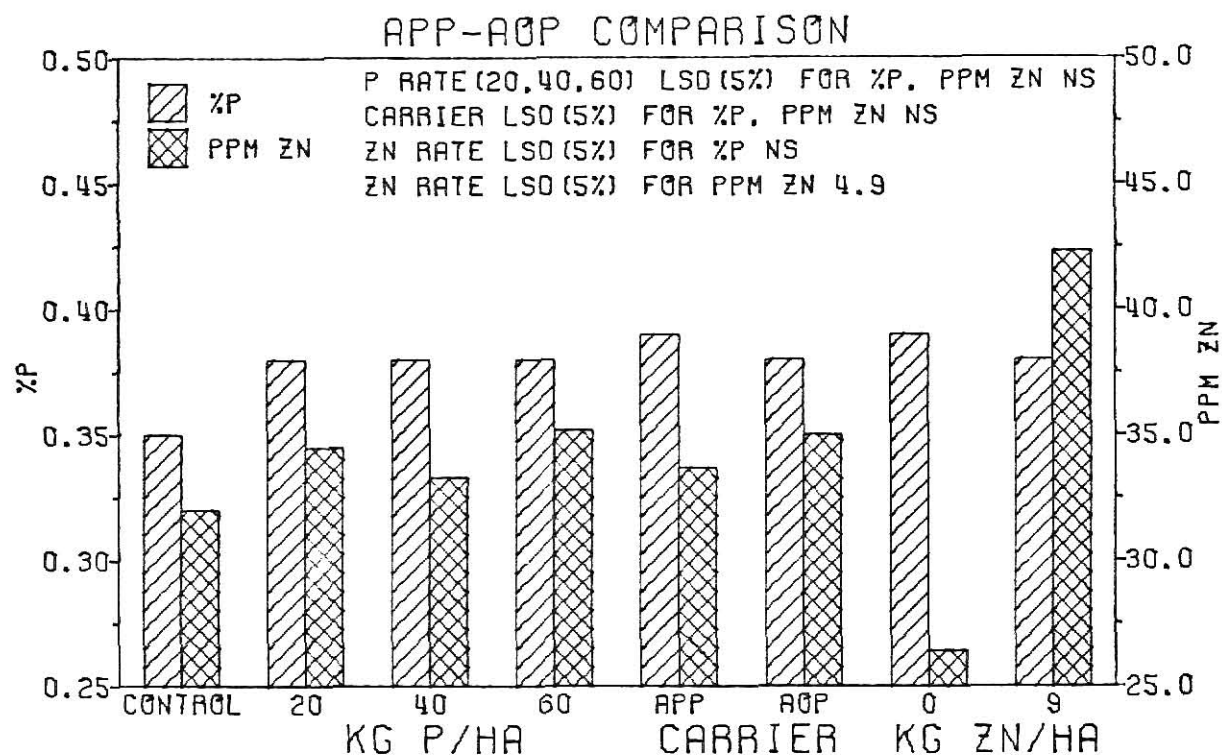


Fig. 11. Effects of P rate, P carrier, and Zn rate on irrigated soybean trifoliolate P and Zn concentrations at early bloom (Compton farm, 1975).

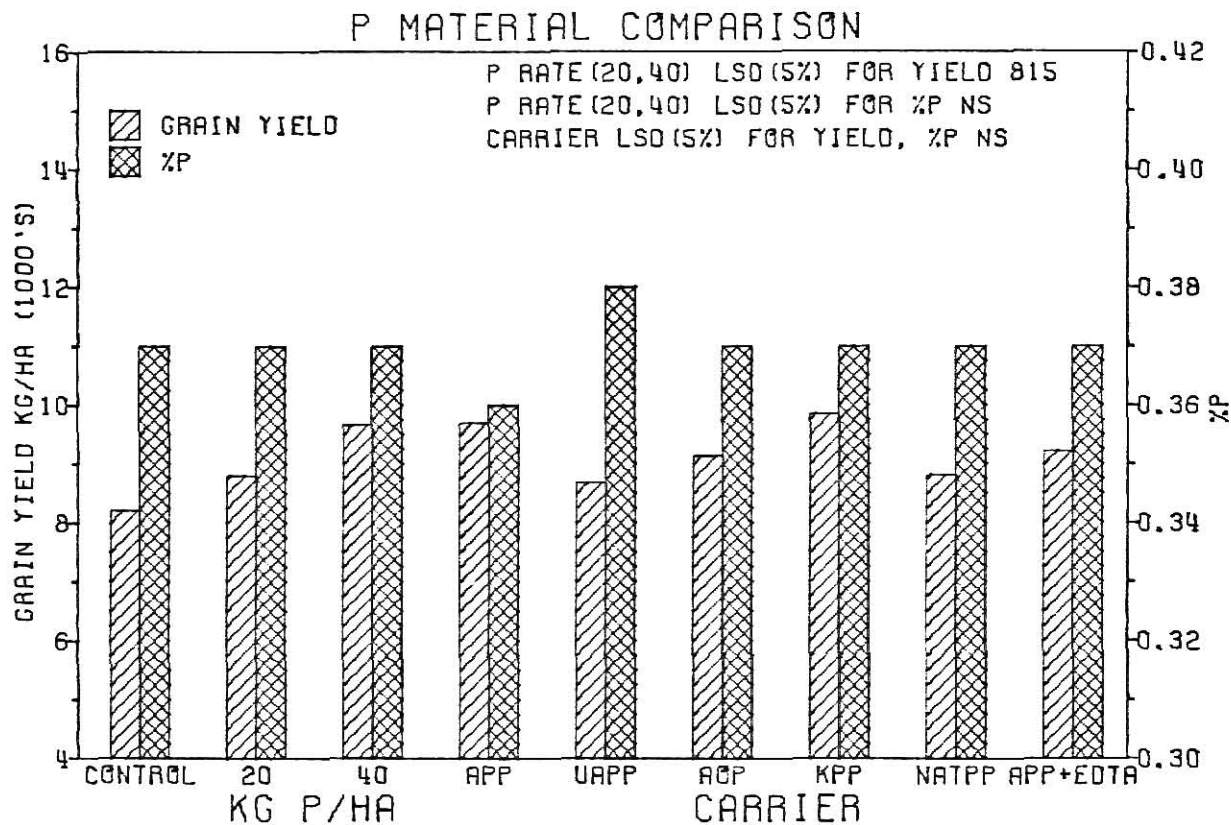


Fig. 12. Effects of P carrier and P rate on irrigated corn grain yields and leaf P concentrations at early sampling (Tribune, 1975).

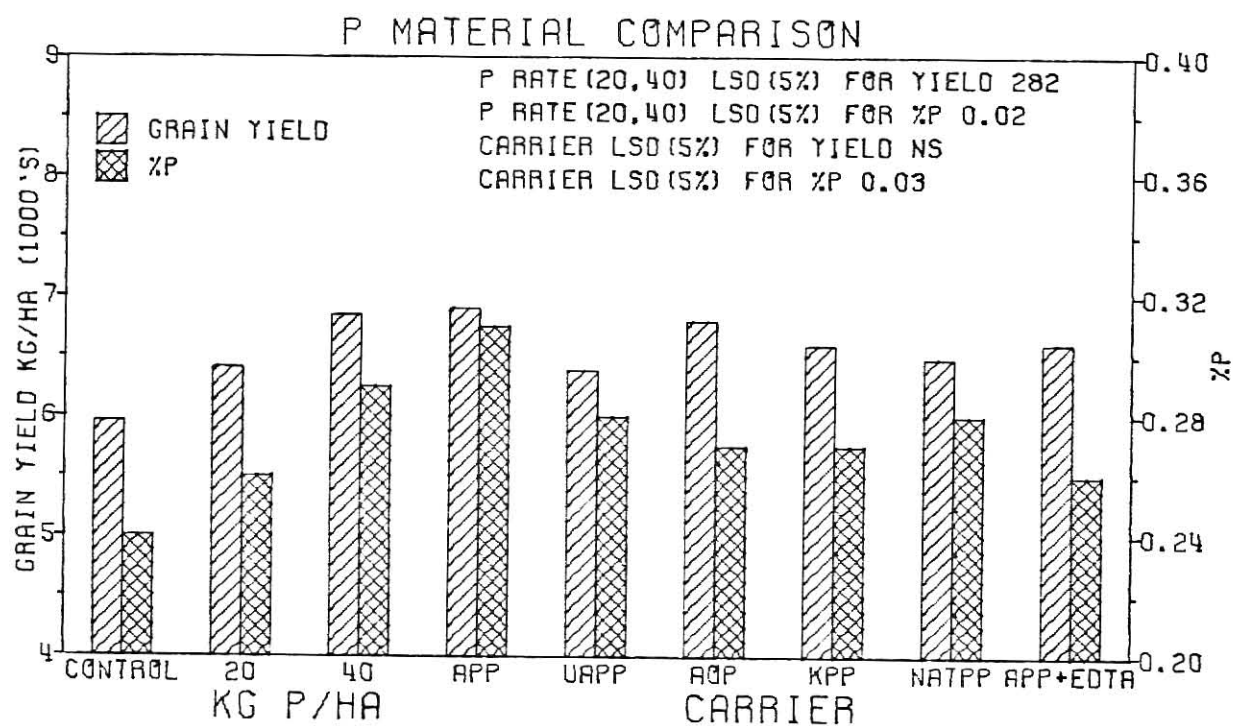


Fig. 13. Effects of P carrier and P rate on irrigated sorghum grain yields and leaf P concentrations at early sampling (Holcomb, 1975).

was 11-16-0 (APP) and the one giving the lowest was 11-16-0 plus EDTA.

These differences were not observed at the late sampling period (Appendix Table VIII).

Significant interactions between P rate and P carrier were found at both Irsik farm locations in 1974 (Fig. 14). In these cases, the effect was on %P at the early sampling date. At the east Irsik location, AOP was superior at 20 kg P/ha and APP was superior at 40 kg P/ha. AOP had dropped to the lowest position in terms of P concentration at the 40 kg P/ha rate. The reason for this switch is not known. At the west location, KPP produced the highest leaf P concentrations at the 20 kg P/ha rate and AOP was highest at the 40 kg P/ha rate. KPP had dropped to the lowest level at the higher rate of P. Again, the reason for these variations are not known.

The possible superiority of a TPP material under high pH and calcareous soil conditions stated by Subbarao (1975) did not materialize in these studies. In fact, at the Tribune location, NaTPP produced the lowest yield of all carriers, although the differences were not significant (Fig. 12 and Appendix Table VIII). At the Holcomb location, NaTPP gave the next lowest yield of all carriers, although again the differences were not statistically significant (Fig. 13 and Appendix Table VIII). All this does not necessarily mean that the NaTPP theory is wrong. It may hold true under more basic-calcareous soil conditions. It should be pointed out that of the studies discussed here, none of the PPP materials have been clearly inferior in supplying P to the plant; so until field conditions can be found where this occurs, a superiority of a TPP material will probably not be found either.

Growth Chamber Studies

The only test crop used with the various soils in the growth chamber studies was corn. Some soils produced two corn crops in succession, others were cropped only once as indicated in the methods and materials section.

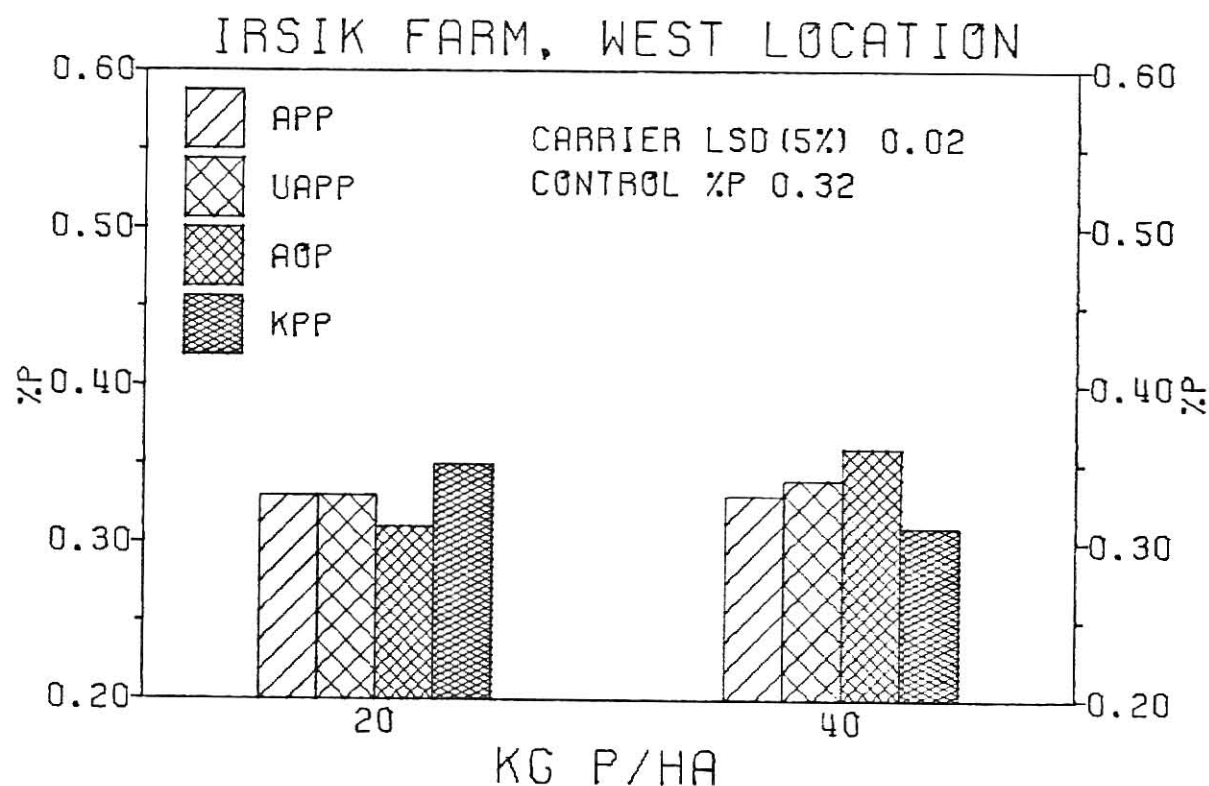
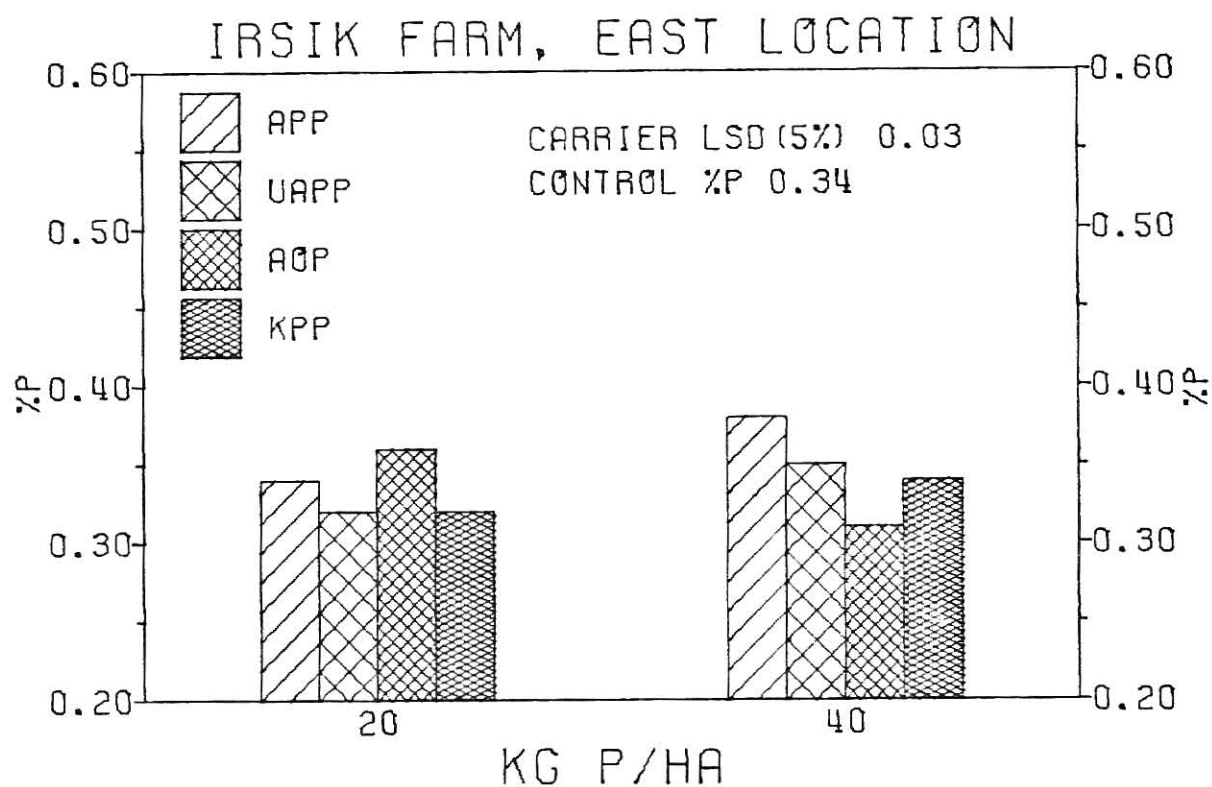


Fig. 14. Irrigated sorghum leaf P concentrations as affected by P rate and P carrier at early sampling (1974).

The individual values represented in the figures presented in this section can also be found in Appendix Tables X-XVII along with any mean and treatment values not presented in the figures. All LSD values at the 5% significance level are also presented in the appendix.

Fresh weight yield data for all studies are not discussed because of close correlation to plant dry weights. The fresh weight data are reported, however, in Appendix Tables X-XIV.

A significant dry weight increase from applied P was recorded for the first crop produced on soil from the Tribune field site (Fig. 15). AOP slightly outyielded APP in the first crop, but essentially no differences were observed in the second crop. This slight superiority of AOP was not significant (Fig. 15 and Appendix Table X).

No response to P application was noted in P concentration in the plant tissue of the first or second crops. Likewise, the two carriers were equal in effect upon %P for both crops (Fig. 15 and Appendix Table X). APP applications were associated with 3 ppm more Zn in the plant than AOP (Fig. 15). This difference was still present in the second crop, although it had narrowed and had become non-significant (Appendix Table X). This trend supports work cited earlier by Allen and Terman (1966) and Ellis (1965). With both corn crops, a good increase in Zn concentration in the plant was obtained with Zn application to the soil (Fig. 15 and Appendix Table X). These differences were highly significant.

A significant interaction between P carrier and Zn application in terms of Zn in the plant was noted also with the Tribune soil on the first crop (Fig. 16). When no Zn was applied, APP and AOP had essentially equal effects on Zn uptake; but when 8 ppm Zn was applied to the soil, APP significantly increased Zn uptake over AOP. This again supports the possible ability of APP to increase Zn uptake over AOP when Zn is applied to the soil.

— A good response to P application occurred with soil from the west Irsik

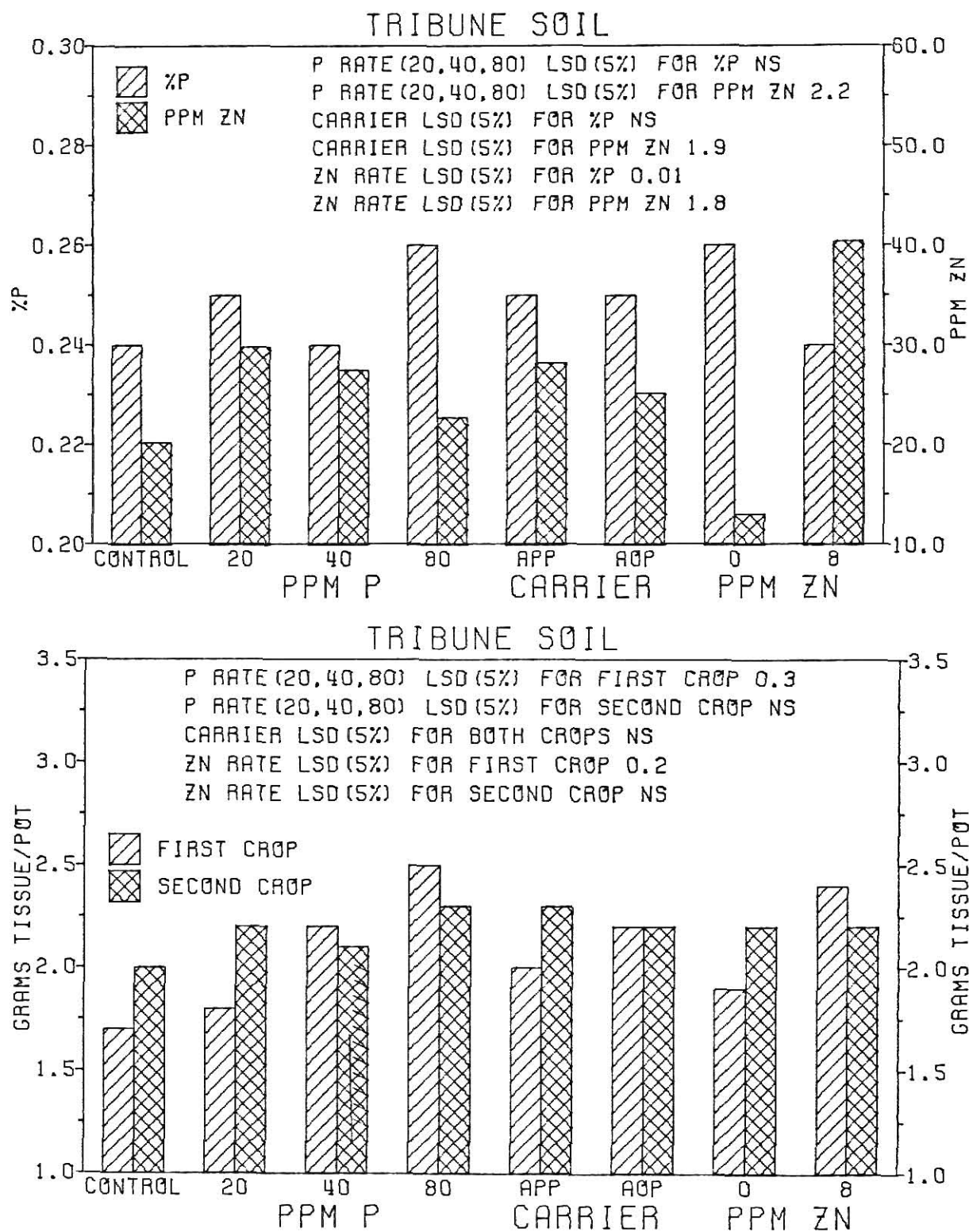


Fig. 15. Effects of P rate, P carrier, and Zn rate on corn dry matter production (two crops) and P and Zn concentrations in the first crop (growth chamber).

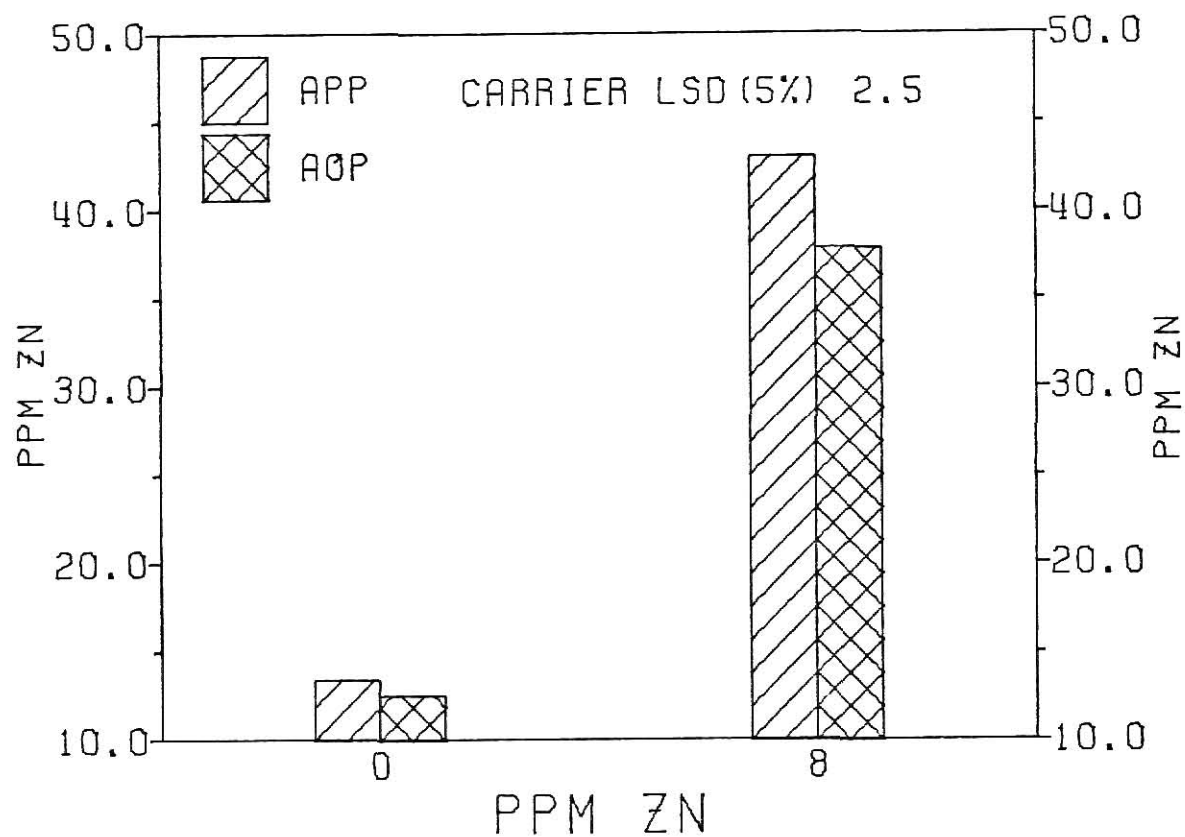


Fig. 16. Corn plant Zn concentrations as affected by P carrier and Zn applications under growth chamber conditions (Tribune soil, first crop). Values have been averaged across P rates.

location (soil pH 7.9) in the first and second crops (Fig. 17 and Appendix Table XI). However, no significant differences between carriers were noted with either crop, although AOP slightly outyielded APP in the first crop. The equality between APP and AOP continued when plant tissue P and Zn concentrations were considered (Fig. 17 and Appendix Table XI).

Applications of P increased plant dry weights with the east Irsik soil (pH 7.2) but only in the first crop (Fig. 18 and Appendix Table XII). AOP slightly outperformed APP on both crops. The differences were not significant on the first crop but were significant for the second. Evidently APP was not able to hydrolyze fast enough to provide an adequate P supply for the second crop. The two carriers had equal influence on plant tissue P concentrations, but APP did significantly outperform AOP by increasing Zn content of the plant more than AOP. This continues to provide support for suggestions of APP superiority over AOP in increasing Zn uptake. Zinc applications significantly increased Zn content of the plant for both crops (Fig. 18 and Appendix Table XII).

Positive response to applied P was found with the Sisk soil (pH 6.6) in terms of plant dry weight (Fig. 19 and Appendix Table XIII). Carrier differences were very small and non-significant. Considering tissue composition, a fair P concentration increase to applied P was noted, but the carriers were identical in effect. AOP slightly increased Zn in the plant over APP, but the difference was not significant.

Dry weight yield increased with applied P on the Burr Oak location soil (pH 8.0) as it did with the Sisk soil (Fig. 20 and Appendix Table XIV). APP and AOP were identical in effect on dry matter production and %P in the plant tissue. Zinc content of the plant was slightly increased by using APP instead of AOP, but not significantly so.

Corn plants grown on the Cotter soil (pH 6.2) responded well to P additions in terms of dry matter production and %P in the plant tissue (Fig.

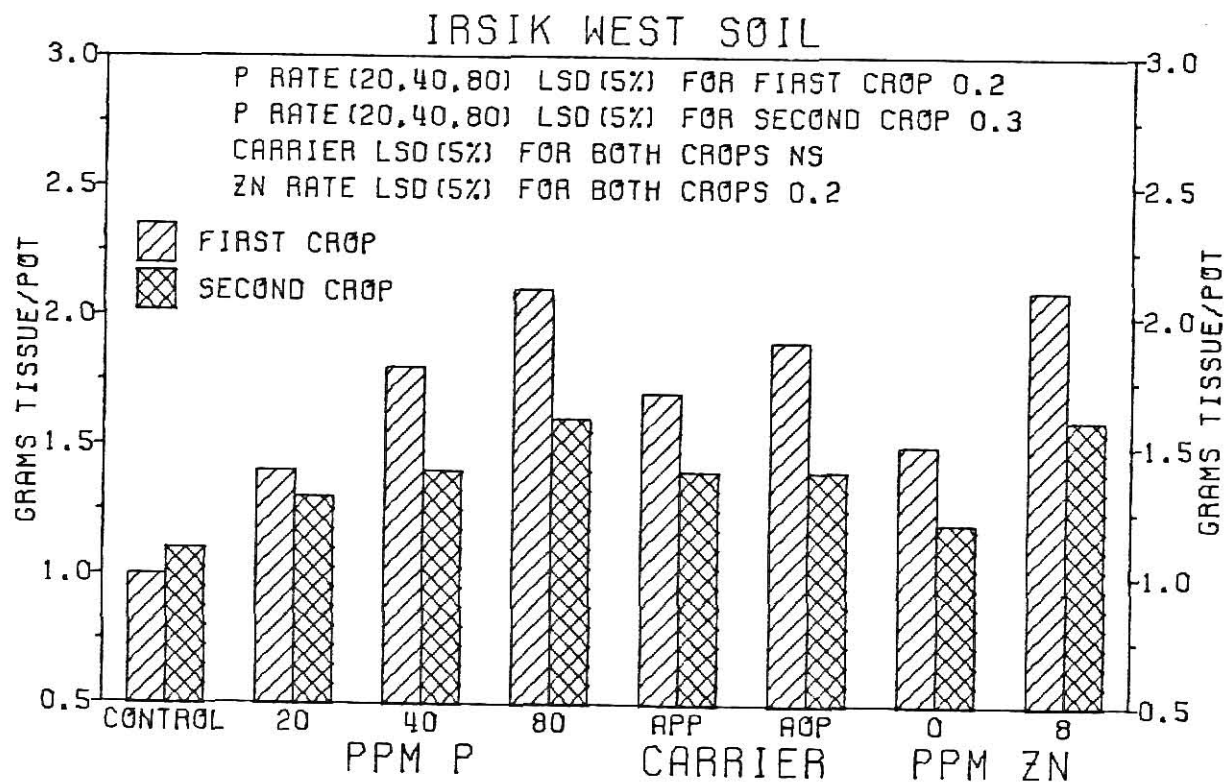
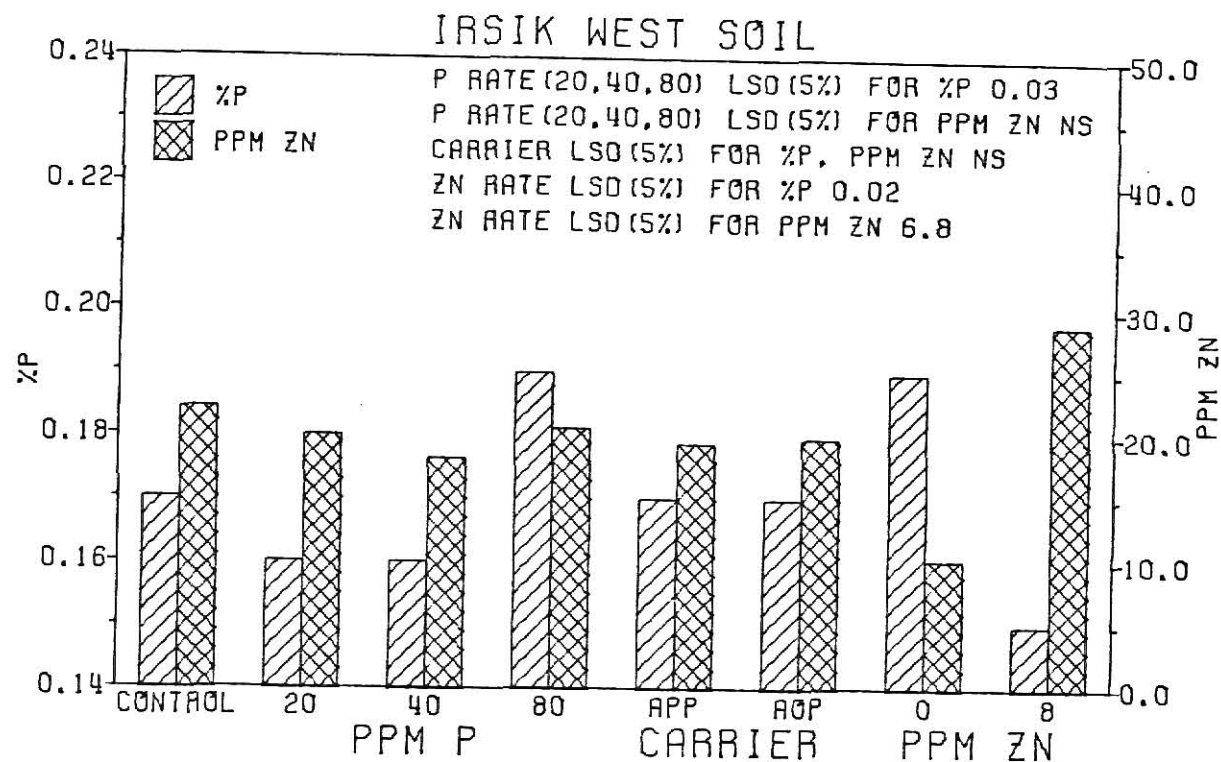


Fig. 17. Effects of P rate, P carrier, and Zn rate on corn dry matter production (two crops) and P and Zn concentrations in the first crop (growth chamber).

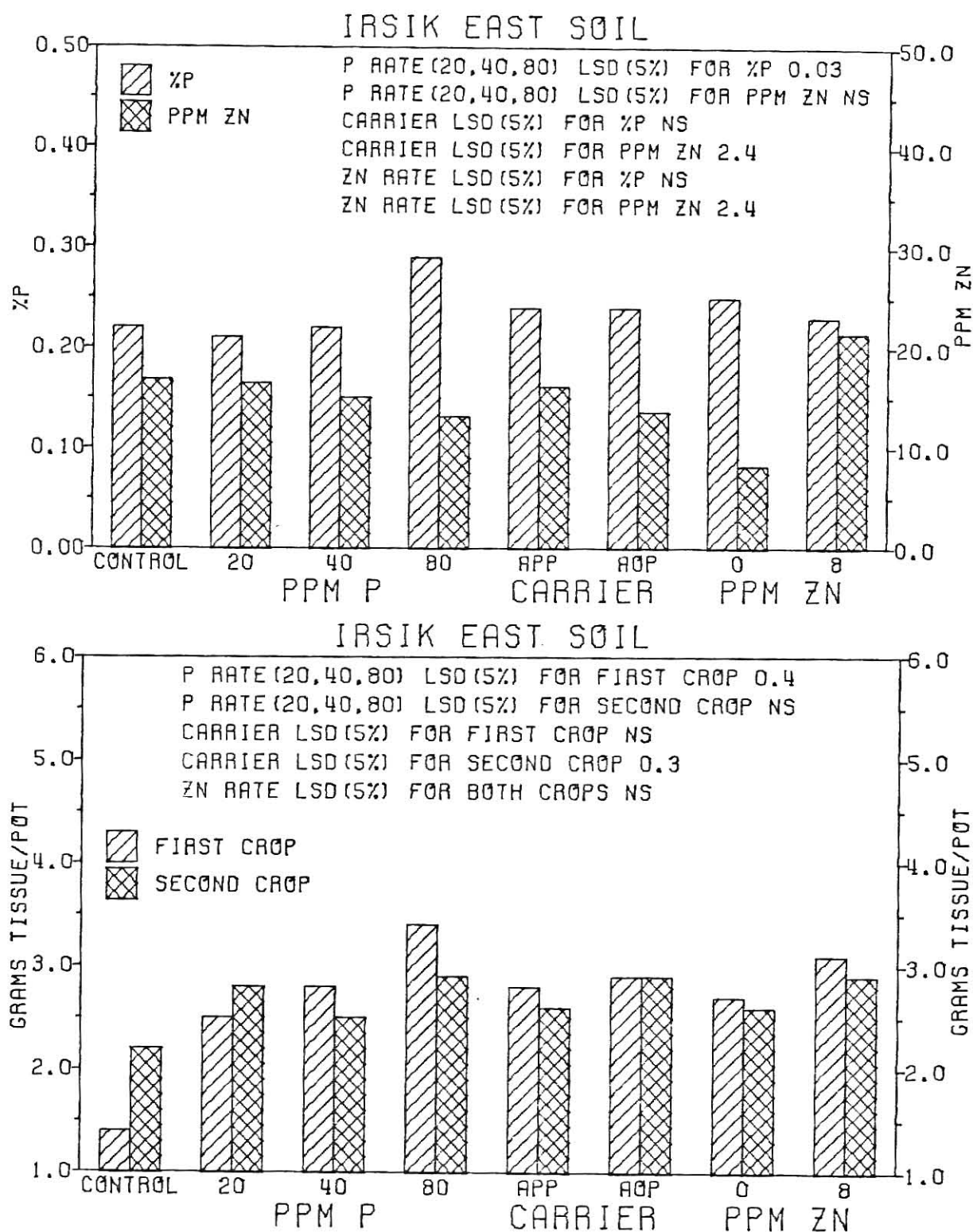


Fig. 18. Effects of P rate, P carrier, and Zn rate on dry matter production (two crops) and plant P and Zn concentrations in the first crop (growth chamber).

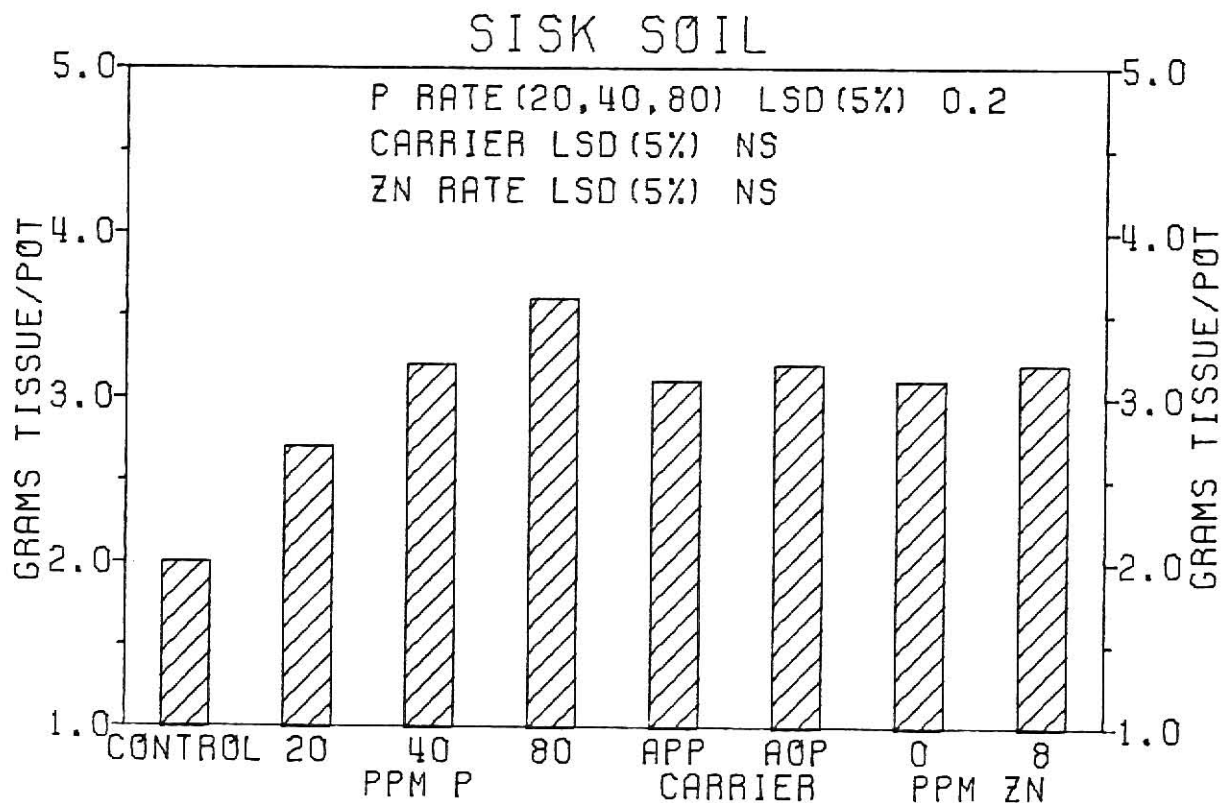
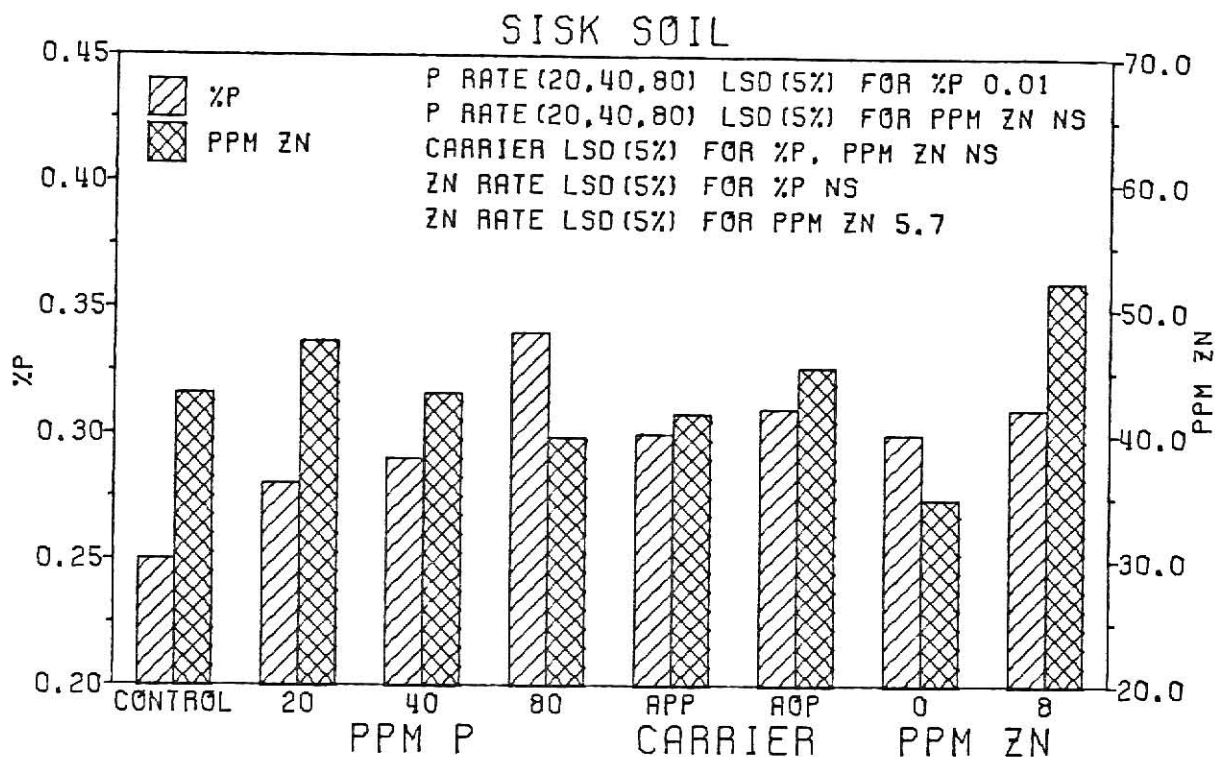


Fig. 19. Effects of P rate, P carrier, and Zn rate on corn dry matter production and plant P and Zn concentrations (growth chamber).

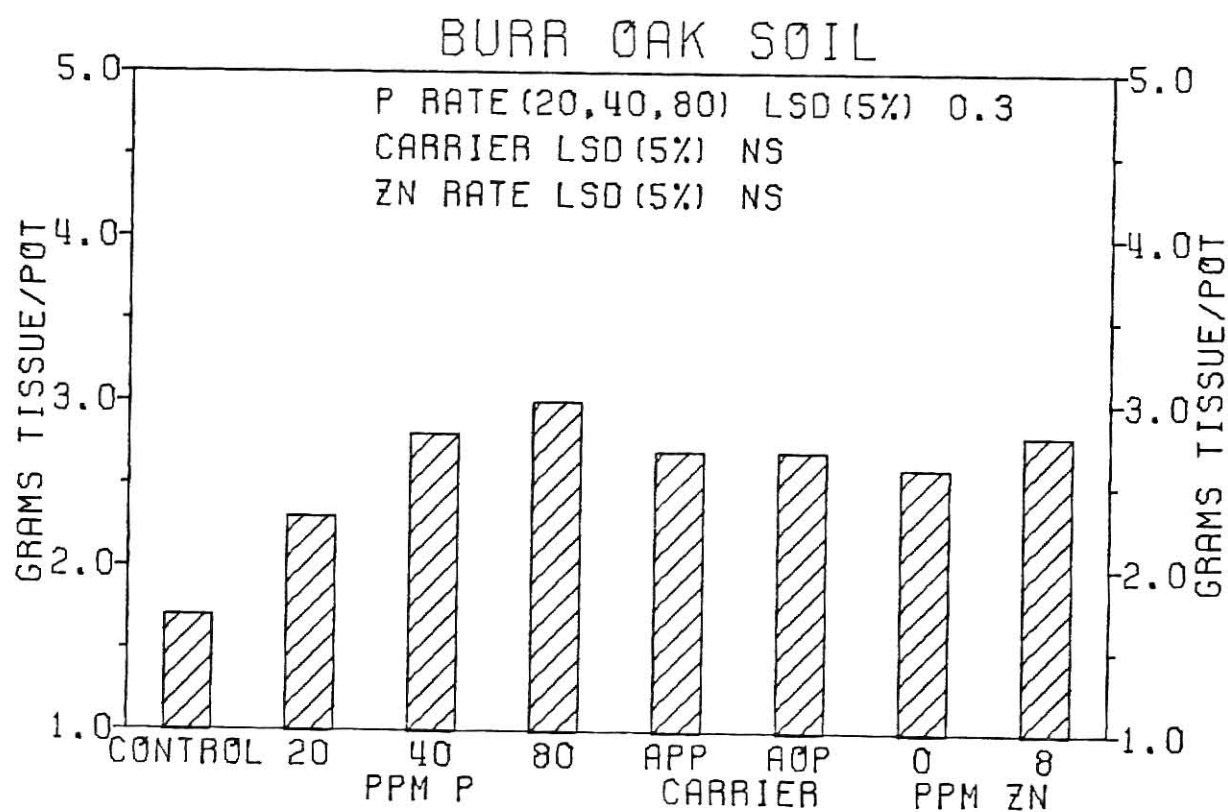
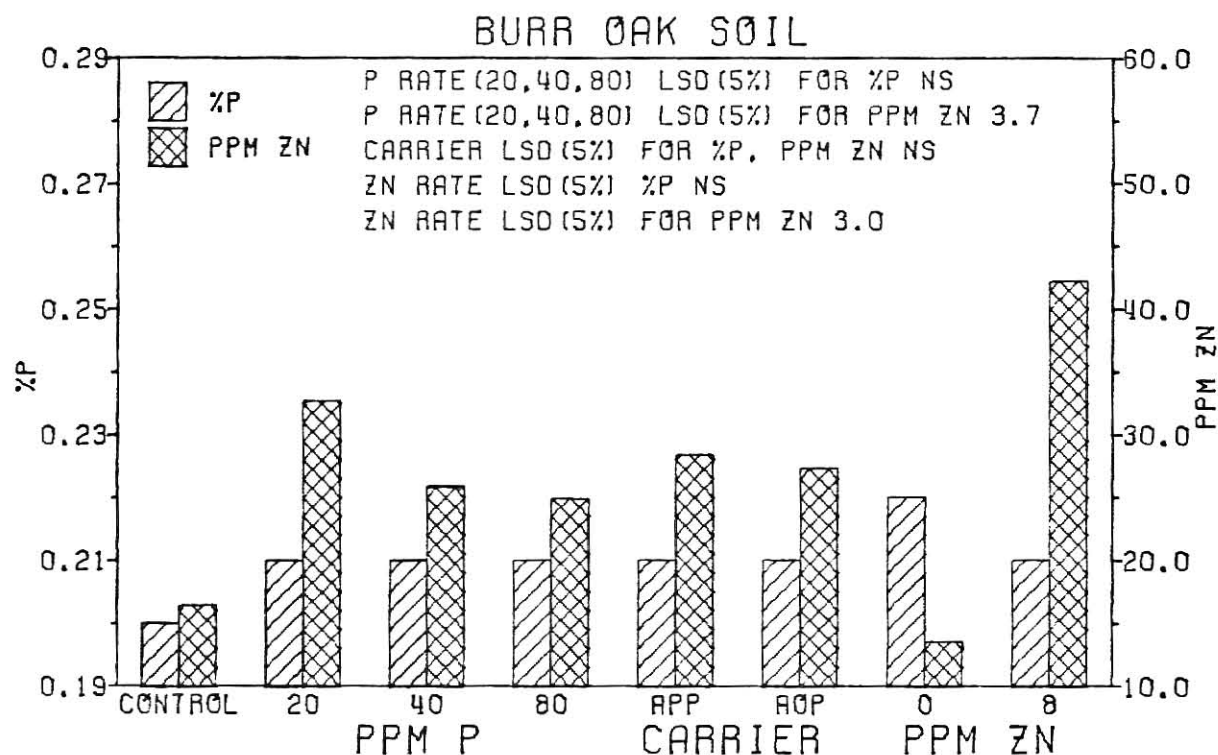


Fig. 20. Effects of P rate, P carrier, and Zn rate on corn dry matter production and P and Zn concentrations (growth chamber).

21 and Appendix Table XIII). A significant increase in dry matter production was observed favoring AOP over APP, however, the reverse was true when %P in the plant was considered. The reason for this reversal is difficult to establish, but it can be noted that the difference was small even though significant. Also, from a statistical viewpoint, when an interaction occurs between several variables, precise statements concerning the means of the variables involved cannot be made. A significant interaction between P carrier, P rate, and Zn rate was observed on plant P concentration with the soil (Fig. 22), so possibly, the superiority of APP over AOP as influencing %P as stated earlier should be taken lightly.

This three-way interaction (Fig. 22) illustrated that when no Zn was applied, APP and AOP were equal in effect on %P in the plant at 20 and 40 ppm rates of P application; but at 80 ppm P, APP topped AOP. With application of Zn, AOP was superior to APP in increasing %P in the plant at the 20 ppm rate of P; but at the 40 and 80 ppm rates of P, the difference disappeared. Exact explanations for these occurrences are difficult.

The soil analysis data from the growth chamber studies showed some interesting trends. Samples taken from the Tribune location soil after the second crop was harvested indicated no effect due to carrier on either Bray P-1 extractable P or DTPA extractable Zn (Appendix Table XV). But the soil sampled between the crops showed two interesting interactions. One between P carrier and Zn rate (Table 11) indicated that the two carriers were equal in effect on DTPA extractable soil Zn when no Zn was applied; but with application of Zn, APP significantly increased extractable Zn over that associated with AOP. An identical relationship was also observed with the Irsik east location soil after the first crop was grown (Table 13). These results support earlier results indicating that APP caused more applied Zn to be absorbed by the plant than did AOP.

A second interaction between P carrier and P rate on available soil Zn

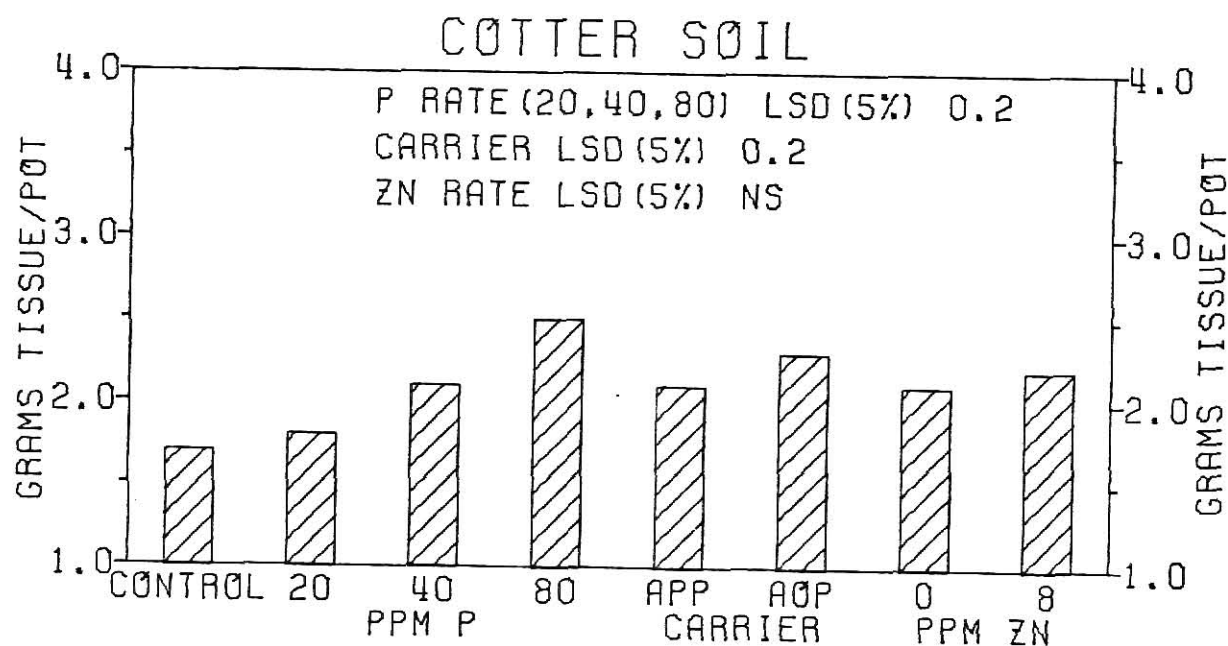
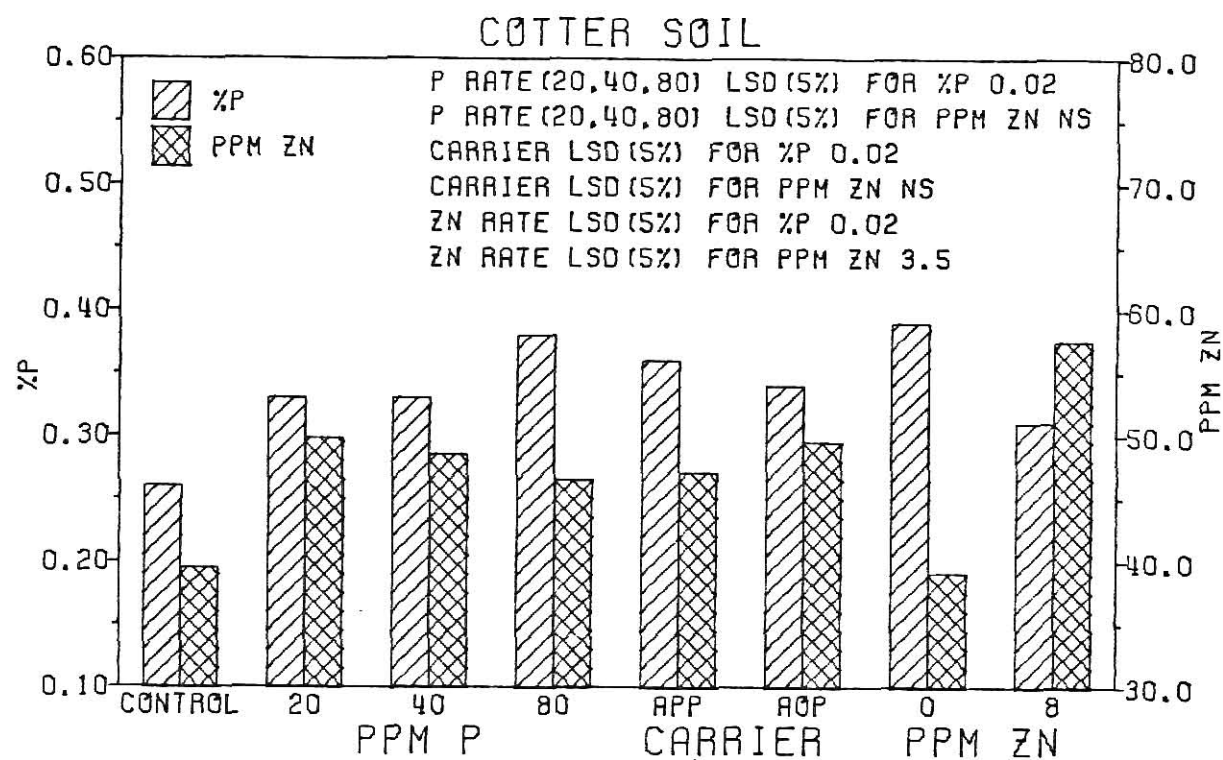


Fig. 21. Effects of P rate, P carrier, and Zn rate on corn dry matter production and P and Zn concentrations (growth chamber).

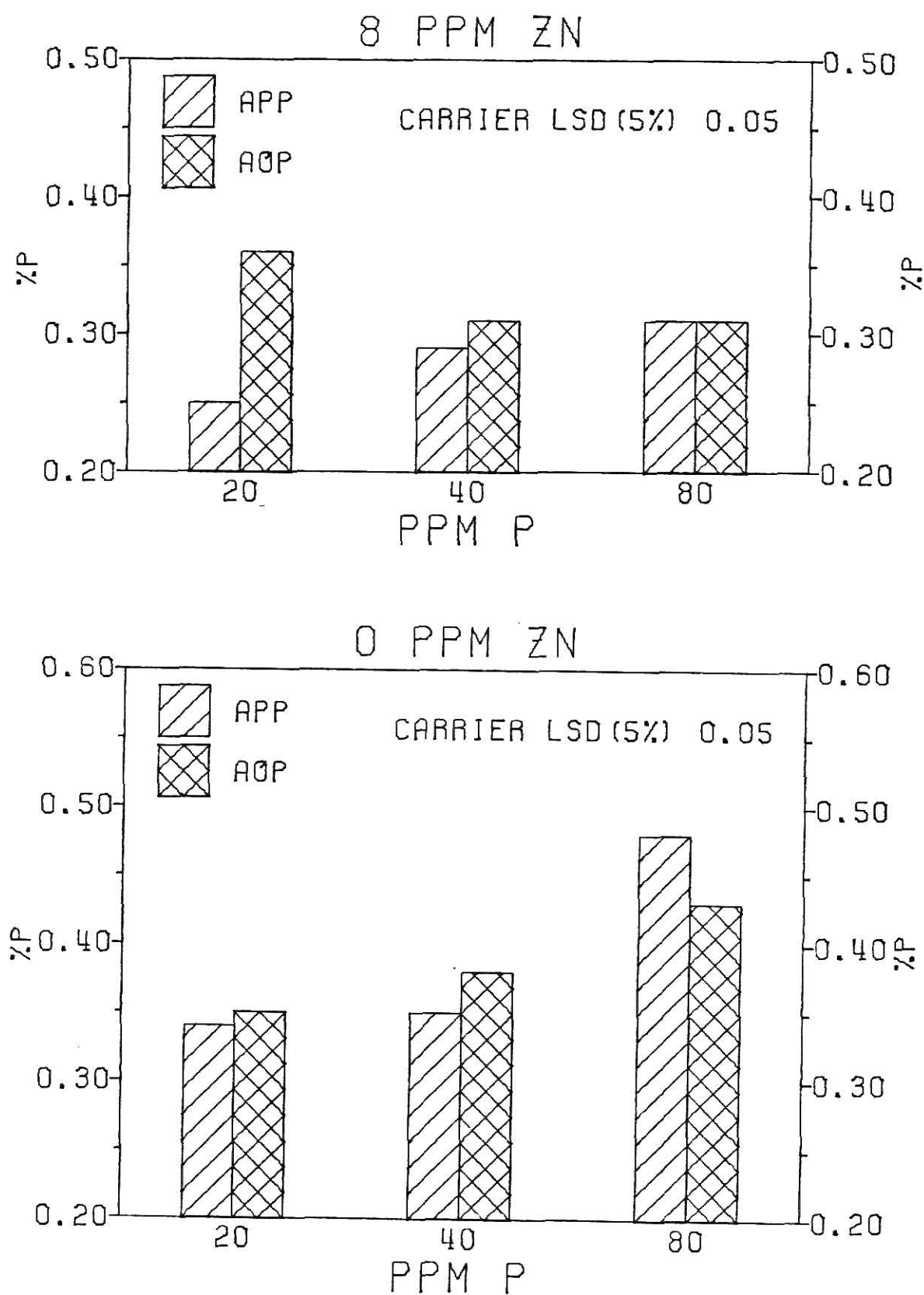


Fig. 22. Effects of Zn, P carrier, and P rate on corn plant P concentrations under growth chamber conditions (Cotter soil).

Table 11. Effects of P carrier and Zn rate on DTPA extractable soil Zn (Tribune soil, after first crop, growth chamber).

P Carrier	Soil Zn (ppm)	
	Zn applied (ppm)	
	0	8
APP	0.77 ^{a/}	3.65
AOP	0.73	3.24
LSD _{.05}	0.20	0.20

^{a/} Mean values averaged across three P rates.

Table 12. Effects of P carrier and P rate on DTPA extractable soil Zn (Tribune soil, after first crop, growth chamber).

P Carrier	Soil Zn (ppm)		
	P applied (ppm)		
	20	40	80
APP	2.12 ^{a/}	2.42	2.10
AOP	2.07	1.90	2.00
LSD _{.05}	0.25	0.25	0.25

^{a/} Mean values averaged across two Zn rates.

Table 13. Effects of P carrier and Zn rate on DTPA extractable soil Zn (Irsik west soil, after first crop, growth chamber).

P Carrier	Soil Zn (ppm)	
	Zn applied (ppm)	
	0	8
APP	0.68 ^{a/}	4.11
AOP	0.81	2.78
LSD _{.05}	0.64	0.64

^{a/} Mean values averaged across three P rates.

Table 14. Effects of P carrier and Zn rate on Bray P-1 extractable soil P (Cotter soil, growth chamber).

P Carrier	Soil P kg/ha	
	Zn applied (ppm)	
	0	8
APP	88 ^{a/}	56
AOP	85	69
LSD _{.05}	8	8

^{a/} Mean values averaged across three P rates.

revealed that APP was related to significantly higher amounts of DTPA extractable Zn in the soil than AOP at the 40 ppm P rate but not at the 20 or 80 ppm P rates (Table 12). The reason for this is not clear.

The Cotter soil showed an interesting interaction between P carrier and Zn rate on Bray P-1 extractable soil P (Table 14). This time, more soil P was made available by AOP than APP when Zn was applied but not when Zn was omitted. The different trend with the Cotter soil could be related to its lower pH and resultant differences in soil chemistry.

CONCLUSIONS

Soils used in this investigation were mostly in the basic pH range. Although none contained large amounts of free calcium carbonate, a problem with availability of P from PPP fertilizers could still exist. Results of this study indicate, however, no clear cut superiority of OP over any of the PPP or TPP fertilizers utilized. In fact, the PPP materials performed as well as OP in influencing yield or P concentration in the plant. There were instances under field and growth chamber conditions in which PPP exceeded the OP product or vice versa, but the differences were small and usually not significant.

Several times the use of APP resulted in more Zn in the plant than the use of AOP. This occurred frequently in the growth chamber studies and occasionally in the field studies. There were instances, too, in the growth chamber when APP increased Zn concentration in plants only when Zn was applied to the soil. Without Zn application, the two carriers were about equally effective in raising plant Zn content. Soil samples collected during and after growth chamber studies indicated repeatedly an increase in DTPA extractable Zn when APP was applied to the soil instead of AOP. These findings offer support to the contention of increased plant Zn concentrations with the use of APP rather than AOP. The sequestering ability of PPP on Zn is most likely the reason for this occurrence.

Suggestions that PPP hydrolysis would be slowed more under high soil pH rather than neutral conditions, thereby reducing P availability to plants as compared to OP, were not substantiated in these studies. Regardless of whether the soil pH was neutral, slightly acid, or in the basic range, the PPP and OP materials performed equally well. Possibly, the biological activity of the basic soils was high enough to allow adequate hydrolysis and so counteracted the reported effect of high pH slowing PPP hydrolysis. According to Sutton and Larsen (1964), enzymatic effects on PPP hydrolysis

are more important than pH, temperature, and other effects so adequate biological or enzymatic activity could be responsible for the equality of P carriers on these soils. If studies could be conducted on high pH, calcareous soils, low in organic matter, a difference might very well be observed between PPP and OP fertilizers. In any case, it is evident that further research into possible situations where PPP may limit P availability under field situations is necessary.

In the studies comparing several P materials at once, no superiority of NaTPP was noted over any other carrier. This finding did not provide supporting data to the hypothesis offered by Subbarao (1975). He stated that because TPP hydrolyzes to one-third OP ions and two-thirds PP, these OP ions would be able to provide P for plant uptake while the PP was hydrolyzing, while a conventional PP material would not be able to provide the OP ions. This is related to his findings that PP tends to form highly insoluble precipitates in calcareous soils. Either these insoluble precipitates were not forming in these soils or they were soluble enough to provide P for the plant. A need certainly exists for research to further evaluate the effects of these reactions under field situations.

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VITA

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APPENDIX

Table I. Effects of P rate, P carrier, and Zn rate on corn yield, leaf composition, and soil P and Zn levels (Tribune Branch Experiment Station, 1974).

Treatments			Grain Yield kg/ha ^{c/}	Leaf Composition ^{a/}				Soil Tests ^{b/}	
P kg/ha	P Carrier	Zn kg/ha		Early %P	Early ppm Zn	Late %P	Late ppm Zn	P kg/ha	Zn ppm
0	---	0	3236	0.32	51.9	0.25	39.5	15	0.45
20	APP ^{d/}	0	3989	0.38	40.5	0.28	33.6	20	0.45
40	APP	0	3939	0.36	48.2	0.29	38.1	12	0.60
20	AOP	0	3870	0.37	56.4	0.27	40.6	17	0.66
40	AOP	0	4284	0.38	40.7	0.27	36.9	17	0.61
0	---	9	3864	0.34	54.2	0.25	46.1	15	0.86
20	APP	9	3562	0.38	49.3	0.27	44.4	19	2.92
40	APP	9	4717	0.38	55.8	0.28	43.9	16	0.84
20	AOP	9	3864	0.35	53.3	0.27	41.4	16	1.05
40	AOP	9	4321	0.38	50.7	0.30	36.3	17	1.07
Treatment LSD _{.05}			608	0.04	NS	0.03	NS	NS	NS
Mean Values									
P rate		20	3820	0.37	49.9	0.27	40.0	17	1.27
		40	4315	0.38	48.8	0.28	38.8	16	0.78
LSD _{.05}			332	NS	NS	NS	NS	NS	NS
P carrier									
		APP	4052	0.37	48.4	0.28	40.0	17	1.20
		AOP	4083	0.37	50.3	0.28	38.8	17	0.85
LSD _{.05}			NS	NS	NS	NS	NS	NS	NS
Zn rate									
		0	4020	0.37	46.5	0.28	37.3	17	0.58
		9	4114	0.37	52.3	0.28	41.5	17	1.47
LSD _{.05}			NS	NS	5.7	NS	4.1	NS	NS

a/ Early sampling was on June 12 and late sampling on July 29.

b/ Samples were taken before application of 1975 materials and analyzed for Bray P-1 available P and DTPA extractable Zn.

c/ Yields were computed at 12.5% moisture.

d/ APP is ammonium polyphosphate and AOP is ammonium orthophosphate.

Table II. Effects of P rate, P carrier, and Zn rate on corn yield and leaf composition (Tribune Branch Experiment Station, 1975).

P kg/ha	Treatments		Zn kg/ha	Grain Yield kg/ha ^{a/}	Leaf Composition ^{c/}			
	P Carrier				Early %P ppm Zn	Late %P ppm Zn		
0	---		0	6648	0.36	41.1	0.22	28.0
20	APP ^{b/}		0	7991	0.43	36.4	0.26	26.1
40	APP		0	9320	0.44	36.6	0.26	24.3
20	AOP		0	9772	0.42	40.6	0.26	31.1
40	AOP		0	9496	0.43	35.9	0.25	23.1
0	---		9	7125	0.36	69.8	0.22	42.1
20	APP		9	8844	0.44	64.4	0.25	41.8
40	APP		9	9929	0.43	60.9	0.28	36.6
20	AOP		9	8674	0.41	64.2	0.26	38.1
40	AOP		9	9214	0.42	66.3	0.27	39.2
Treatment LSD _{.05}				1267	0.04	9.5	0.02	8.2
Mean Values								
P rate	20			8818	0.42	51.4	0.26	34.3
	40			9490	0.43	49.9	0.26	30.8
LSD _{.05}				652	NS	NS	NS	NS
P carrier								
	APP			9019	0.43	49.6	0.26	32.2
	AOP			9289	0.42	51.8	0.26	32.9
LSD _{.05}				NS	NS	NS	NS	NS
Zn rate								
	0			9145	0.43	37.4	0.26	26.2
	9			9163	0.43	64.0	0.26	38.9
LSD _{.05}				NS	NS	4.4	NS	3.8

a/ Yields were computed at 12.5% moisture.

b/ APP is ammonium polyphosphate and AOP is ammonium orthophosphate.

c/ Early sampling was on June 24 and late sampling on July 29.

Table III. Effects of P rate, P carrier, and Zn rate on grain sorghum yield and leaf composition (Holcomb Irrigation Field, 1975).

P kg/ha	Treatments P Carrier	Zn kg/ha	Grain Yield kg/ha ^{b/}	Leaf Composition ^{a/}			
				Early %P	Early ppm Zn	Late %P	Late ppm Zn
0	---	0	5093	0.27	49.7	0.25	35.1
20	APP ^{c/}	0	5751	0.34	38.5	0.29	29.8
40	APP	0	6611	0.39	46.4	0.30	35.1
60	APP	0	6247	0.37	37.4	0.31	31.6
20	AOP	0	5306	0.32	31.1	0.29	28.2
40	AOP	0	6435	0.34	39.6	0.30	33.2
60	AOP	0	6510	0.37	41.1	0.30	30.6
20	APP	4.5	6027	0.30	39.9	0.27	34.2
40	APP	4.5	5839	0.34	36.3	0.29	33.2
60	APP	4.5	6410	0.38	40.5	0.30	31.7
20	AOP	4.5	5927	0.29	35.7	0.27	29.3
40	AOP	4.5	6517	0.34	34.1	0.29	29.2
60	AOP	4.5	6372	0.35	40.9	0.30	32.8
0	---	4.5	4905	0.26	42.8	0.25	31.7
Treatment LSD _{.05}			935	0.05	NS	0.02	NS
Mean Values							
P rate		20	5751	0.31	36.3	0.28	30.4
		40	6354	0.35	39.1	0.29	32.7
		60	6385	0.37	40.0	0.30	31.7
LSD _{.05}			485	0.03	NS	0.01	NS
P carrier							
		APP	6147	0.35	39.8	0.29	32.6
		AOP	6178	0.33	37.1	0.29	30.6
LSD _{.05}			NS	NS	NS	NS	NS
Zn rate		0	6140	0.35	39.0	0.30	31.4
		4.5	6184	0.33	37.9	0.29	31.8
LSD _{.05}			NS	0.02	NS	0.01	NS

a/ Early sampling was on July 25 and late sampling on August 13.

b/ Yields were computed at 12.5% moisture.

c/ APP is ammonium polyphosphate and AOP is ammonium orthophosphate.

Table IV. Effects of P rate, P carrier, and Zn rate on grain sorghum leaf composition (Irsik farm, west location, 1974).

Treatments			Leaf Composition ^{a/}			
P kg/ha	P Carrier	Zn kg/ha	Early %P	Early ppm Zn	Late %P	Late ppm Zn
0	---	0	0.26	26.7	0.32	42.9
20	APP ^{b/}	0	0.30	23.0	0.34	32.6
40	APP	0	0.30	19.1	0.36	26.8
60	APP	0	0.31	20.1	0.39	30.0
20	AOP	0	0.27	26.1	0.32	31.9
40	AOP	0	0.30	25.1	0.35	25.4
60	AOP	0	0.30	23.2	0.36	26.5
20	APP	4.5	0.27	24.3	0.34	29.5
40	APP	4.5	0.28	23.1	0.35	33.3
60	APP	4.5	0.31	25.1	0.38	28.2
20	AOP	4.5	0.27	26.8	0.34	37.6
40	AOP	4.5	0.31	27.2	0.35	34.8
60	AOP	4.5	0.30	27.1	0.34	40.9
Treatment LSD _{.05}			NS	NS	0.03	NS
Mean Values						
P rate	20		0.28	25.1	0.33	32.9
	40		0.28	22.0	0.33	27.8
	60		0.30	23.9	0.37	31.4
LSD _{.05}			NS	NS	NS	NS
P carrier						
	APP		0.29	22.5	0.36	30.1
	AOP		0.28	24.9	0.33	31.3
LSD _{.05}			NS	NS	0.03	NS
Zn rate						
	0		0.29	22.8	0.35	28.9
	4.5		0.28	24.6	0.33	32.5
LSD _{.05}			NS	NS	NS	NS

a/ Early sampling was on July 10 and late sampling on August 9.

b/ APP is ammonium polyphosphate and AOP is ammonium orthophosphate.

Table V. Effects of P rate, P carrier, and Zn rate on grain sorghum leaf composition (Irsik farm, east location, 1974).

P kg/ha	Treatments P Carrier	Zn kg/ha	Leaf Composition ^{a/}			
			Early %P	Early ppm Zn	Late %P	Late ppm Zn
0	---	0	0.29	29.1	0.37	35.3
20	APP ^{b/}	0	0.31	28.7	0.41	33.2
40	APP	0	0.30	31.8	0.41	30.9
60	APP	0	0.32	25.2	0.44	31.0
20	AOP	0	0.28	27.3	0.39	34.0
40	AOP	0	0.31	26.5	0.40	32.7
60	AOP	0	0.32	37.3	0.43	29.5
20	APP	4.5	0.28	38.3	0.41	35.6
40	APP	4.5	0.32	32.3	0.40	33.5
60	APP	4.5	0.31	30.8	0.43	33.5
20	AOP	4.5	0.32	36.1	0.38	35.8
40	AOP	4.5	0.29	23.8	0.39	36.1
60	AOP	4.5	0.31	39.5	0.43	34.4
Treatment LSD _{.05}			0.03	NS	0.03	NS
Mean Values						
P rate	20		0.29	32.6	0.40	34.7
	40		0.30	28.6	0.40	33.3
	60		0.31	33.2	0.43	32.1
LSD _{.05}			0.01	NS	0.02	NS
P carrier						
	APP		0.30	31.2	0.42	33.0
	AOP		0.30	31.7	0.40	33.8
LSD _{.05}			NS	NS	NS	NS
Zn rate	0		0.30	29.5	0.41	31.9
	4.5		0.30	33.5	0.41	34.8
LSD _{.05}			NS	NS	NS	2.0

^{a/} Early sampling was on July 9 and late sampling on August 9.

^{b/} APP is ammonium polyphosphate and AOP is ammonium orthophosphate.

Table VI. Effects of P rate, P carrier, and Zn rate on soybean yield and trifoliolate composition (Compton farm, 1974).

P kg/ha	Treatments P Carrier	Zn kg/ha	Grain Yield kg/ha ^{b/}	Trifoliolate Composition ^{a/}			
				Early %P	Early ppm Zn	Late %P	Late ppm Zn
0	---	0	1800	0.28	24.2	0.30	29.3
20	APP ^{c/}	0	1819	0.23	15.6	0.33	23.8
40	APP	0	1819	0.31	17.0	0.38	31.2
60	APP	0	1963	0.38	20.2	0.36	14.9
20	AOP	0	2195	0.29	15.5	0.35	14.7
40	AOP	0	1518	0.33	14.1	0.39	19.3
60	AOP	0	1900	0.33	10.0	0.41	42.2
20	APP	9	2258	0.27	25.3	0.34	43.4
40	APP	9	2201	0.26	25.9	0.36	42.0
60	APP	9	1976	0.28	30.2	0.59	43.9
20	AOP	9	1631	0.25	28.1	0.32	41.1
40	AOP	9	2377	0.31	30.3	0.34	39.3
60	AOP	9	1988	0.32	31.4	0.35	40.1
Treatment LSD .05			NS	NS	11.7	NS	21.9
Mean Values							
P rate	20		1976	0.26	21.1	0.33	30.8
	40		1976	0.30	21.8	0.37	33.0
	60		1957	0.33	22.9	0.43	35.3
LSD .05			NS	0.06	NS	NS	NS
P carrier							
	APP		2007	0.29	22.4	0.32	33.2
	AOP		1932	0.31	21.6	0.36	32.8
LSD .05			NS	NS	NS	NS	NS
Zn rate	0		1869	0.31	15.4	0.37	24.4
	9		2070	0.28	28.5	0.38	41.6
LSD .05			NS	NS	4.9	NS	9.3

a/ Early sampling was on July 9 and late sampling on August 8.

b/ Yields were computed at 12.5% moisture.

c/ APP is ammonium polyphosphate and AOP is ammonium orthophosphate.

Table VII. Residual effects of P rate, P carrier, and Zn rate on soybean yield and trifoliolate composition (Compton farm, 1975).

P kg/ha	Treatments		Zn kg/ha	Grain Yield kg/ha ^{b/}	Trifoliolate Composition ^{a/}	
	P Carrier				%P	ppm Zn
0	---		0	2183	0.35	32.0
20	APP ^{c/}		0	2151	0.39	32.4
40	APP		0	2195	0.38	22.9
60	APP		0	2063	0.38	22.3
20	AOP		0	2296	0.38	24.6
40	AOP		0	2151	0.38	28.2
60	AOP		0	2139	0.39	27.8
20	APP		9	2371	0.38	36.3
40	APP		9	2339	0.37	40.0
60	APP		9	2383	0.40	48.2
20	AOP		9	2239	0.36	44.7
40	AOP		9	3117	0.38	42.2
60	AOP		9	2038	0.35	42.4
Treatment LSD _{.05}				NS	NS	11.7
Mean Values						
P rate	20			2264	0.38	34.5
	40			2452	0.38	33.3
	60			2158	0.38	35.2
	LSD _{.05}			NS	NS	NS
P carrier						
	APP			2252	0.39	33.7
	AOP			2333	0.38	35.0
	LSD _{.05}			NS	NS	NS
Zn rate	0			2164	0.39	26.4
	9			2415	0.38	42.3
	LSD _{.05}			NS	NS	4.9

a/ Samples were taken on July 28.

b/ Yields were computed at 12.5% moisture.

c/ APP is ammonium polyphosphate and AOP is ammonium orthophosphate.

Table VIII. Effects of P rate and P carrier on grain sorghum and corn grain yield and leaf composition (Tribune Branch Experiment Station and Holcomb Irrigation Field, 1975).

Treatments		Tribune Corn			Holcomb Sorghum		
P	P	Yield ^{c/} kg/ha	Leaf %P Composition ^{a/}		Yield ^{c/} kg/ha	Leaf %P Composition ^{b/}	
kg/ha	Carrier		Early	Late		Early	Late
0	---	8210	0.37	0.23	5958	0.24	0.22
20	APP ^{d/}	8956	0.37	0.23	6460	0.29	0.22
40	APP	10418	0.36	0.23	7345	0.32	0.27
20	UAPP	8913	0.37	0.24	6241	0.26	0.24
40	UAPP	8467	0.38	0.24	6529	0.30	0.26
20	AOP	9609	0.36	0.22	6429	0.26	0.24
40	AOP	8687	0.38	0.24	7163	0.29	0.26
20	KPP	8473	0.37	0.23	6222	0.26	0.24
40	KPP	11221	0.37	0.24	6981	0.28	0.26
20	NaTPP	7796	0.37	0.23	6429	0.26	0.24
40	NaTPP	9834	0.37	0.24	6542	0.30	0.27
20	APP+EDTA	9057	0.36	0.22	6686	0.26	0.25
40	APP+EDTA	9377	0.38	0.24	6535	0.26	0.25
Treatment LSD .05		NS	NS	NS	684	0.04	0.02
Mean Values							
P rate 20		8800	0.37	0.23	6410	0.26	0.25
40		9665	0.37	0.24	6849	0.29	0.26
LSD .05		815	NS	NS	282	0.02	0.01
P carrier							
APP		9597	0.36	0.23	6905	0.31	0.26
UAPP		8687	0.38	0.24	6385	0.28	0.25
AOP		9145	0.37	0.23	6799	0.27	0.25
KPP		9847	0.37	0.24	6598	0.27	0.25
NaTPP		8812	0.37	0.24	6485	0.28	0.26
APP+EDTA		9220	0.37	0.23	6611	0.26	0.25
LSD .05		NS	NS	NS	NS	0.03	NS

a/ Early sampling was on June 24 and late sampling on July 29.

b/ Early sampling was on July 25 and late sampling on August 13.

c/ Yields were computed at 12.5% moisture.

d/ APP is ammonium polyphosphate, UAPP is urea ammonium polyphosphate, AOP is ammonium orthophosphate, KPP is potassium polyphosphate, NaTPP is sodium tripolyphosphate, and APP+EDTA is ammonium polyphosphate plus EDTA.

Table IX. Effects of P rate and P carrier on grain sorghum leaf composition (Irsik farm, east and west locations, 1974).

Treatments		West Location		East Location	
P	P	Leaf %P Composition ^{a/}		Leaf %P Composition ^{b/}	
kg/ha	Carrier	Early	Late	Early	Late
0	---	0.32	0.33	0.34	0.36
20	APP ^{c/}	0.33	0.39	0.34	0.40
40	APP	0.33	0.37	0.38	0.44
20	UAPP	0.33	0.36	0.32	0.41
40	UAPP	0.34	0.42	0.35	0.43
20	AOP	0.31	0.38	0.36	0.41
40	AOP	0.36	0.40	0.31	0.43
20	KPP	0.35	0.37	0.32	0.40
40	KPP	0.31	0.43	0.34	0.39
Treatment LSD _{.05}		NS	NS	NS	0.05
Mean Values					
P rate	20	0.33	0.37	0.33	0.41
	40	0.33	0.41	0.34	0.42
LSD _{.05}		NS	NS	NS	NS
P carrier					
	APP	0.33	0.38	0.36	0.42
	UAPP	0.34	0.39	0.33	0.42
	AOP	0.34	0.39	0.33	0.42
	KPP	0.33	0.40	0.33	0.39
LSD _{.05}		NS	NS	NS	NS

a/ Early sampling was on July 10 and late sampling on August 9.

b/ Early sampling was on July 9 and late sampling on August 9.

c/ APP is ammonium polyphosphate, UAPP is urea ammonium polyphosphate, AOP is ammonium orthophosphate, and KPP is potassium polyphosphate.

Table X. Effects of P rate, P carrier, and Zn rate on corn plant yield and composition in the growth chamber (Tribune soil).

Treatments			First Crop				Second Crop			
			Yield		Plant		Yield		Plant	
P	P	Zn	Fresh	Dry	Composition		Fresh	Dry	Composition	
ppm	Carrier	ppm	g/pot	g/pot	%P	ppm Zn	g/pot	g/pot	%P	ppm Zn
0	---	0	16.7	1.7	0.24	20.2	24.6	2.0	0.35	16.5
20	AOP ^{a/}	0	19.7	1.7	0.25	15.0	25.6	1.9	0.31	9.9
40	AOP	0	23.5	2.0	0.27	13.0	26.3	2.1	0.34	10.5
80	AOP	0	28.2	2.4	0.27	9.5	28.4	2.3	0.36	10.2
20	APP	0	18.9	1.5	0.26	16.2	29.8	2.5	0.33	10.2
40	APP	0	23.2	2.0	0.25	12.6	29.1	2.4	0.35	10.8
80	APP	0	26.7	2.1	0.27	11.5	26.4	2.0	0.37	11.6
20	AOP	8	24.3	2.0	0.23	42.1	27.0	2.2	0.33	35.2
40	AOP	8	27.2	2.6	0.22	38.0	24.0	1.9	0.35	29.7
80	AOP	8	30.9	2.8	0.25	33.3	29.4	2.6	0.32	27.7
20	APP	8	23.6	1.8	0.25	45.9	26.9	2.0	0.35	33.3
40	APP	8	24.7	2.2	0.24	46.4	26.8	2.1	0.35	34.0
80	APP	8	30.5	2.8	0.24	36.7	29.3	2.5	0.37	31.4
Treatment LSD _{.05}			5.0	0.6	0.03	5.5	NS	NS	NS	6.9
Mean Values										
P rate			20	21.6	1.8	0.25	29.8	27.3	2.2	0.33
			40	24.6	2.2	0.24	27.5	26.5	2.1	0.34
			80	29.0	2.5	0.26	22.7	28.3	2.3	0.36
LSD _{.05}				2.6	0.3	NS	2.2	NS	NS	NS
P carrier										
			APP	24.6	2.0	0.25	28.2	28.0	2.3	0.35
			AOP	25.6	2.2	0.25	25.1	26.8	2.2	0.33
LSD _{.05}				NS	NS	NS	1.9	NS	NS	NS
Zn rate										
			0	23.4	1.9	0.26	13.0	27.6	2.2	0.34
			8	26.8	2.4	0.24	40.4	27.2	2.2	0.35
LSD _{.05}				2.1	0.2	0.01	1.8	NS	NS	2.4

a/ AOP is ammonium orthophosphate and APP is ammonium polyphosphate.

Table XI. Effects of P rate, P carrier, and Zn rate on corn plant yield and composition in the growth chamber (Irsik west soil).

Treatments			First Crop				Second Crop			
			Yield		Plant		Yield		Plant	
P ppm	P Carrier	Zn ppm	Fresh g/pot	Dry g/pot	Composition %P	ppm Zn	Fresh g/pot	Dry g/pot	Composition %P	ppm Zn
0	---	0	11.5	1.0	0.17	22.1	12.6	1.1	0.23	14.6
20	AOP ^{a/}	0	15.3	1.3	0.16	8.0	14.5	1.1	0.28	15.6
40	AOP	0	17.7	1.6	0.17	9.6	14.1	1.0	0.32	12.3
80	AOP	0	23.1	1.9	0.24	8.7	20.5	1.8	0.37	10.9
20	APP	0	14.5	1.2	0.16	8.6	17.1	1.3	0.29	12.2
40	APP	0	15.6	1.6	0.20	9.9	16.7	1.2	0.32	13.0
80	APP	0	20.3	1.6	0.21	16.6	15.3	1.1	0.34	12.2
20	AOP	8	15.9	1.7	0.16	32.4	17.0	1.4	0.26	48.0
40	AOP	8	21.7	2.0	0.14	28.5	17.4	1.4	0.28	39.8
80	AOP	8	27.4	2.6	0.16	31.6	20.4	1.9	0.28	37.3
20	APP	8	17.2	1.5	0.15	30.9	16.8	1.4	0.26	44.4
40	APP	8	20.8	2.0	0.14	24.7	20.6	1.8	0.25	40.5
80	APP	8	25.1	2.4	0.14	25.6	20.0	1.8	0.29	34.4
Treatment LSD _{.05}			3.5	0.5	0.05	17.9	4.6	0.5	0.04	4.8
Mean Values										
P rate			20	15.8	1.4	0.16	20.0	16.3	1.3	0.27
			40	19.0	1.8	0.16	18.2	17.2	1.4	0.29
			80	24.0	2.1	0.19	20.6	19.1	1.6	0.32
LSD _{.05}				1.9	0.2	0.03	NS	NS	0.3	0.02
P carrier										
			APP	18.9	1.7	0.17	19.4	17.8	1.4	0.29
			AOP	20.2	1.9	0.17	19.8	17.3	1.4	0.30
LSD _{.05}				NS	NS	NS	NS	NS	NS	NS
Zn rate			0	17.8	1.5	0.19	10.2	16.4	1.2	0.32
			8	21.4	2.1	0.15	28.9	18.7	1.6	0.27
LSD _{.05}				1.5	0.2	0.02	6.8	2.0	0.2	0.02

^{a/} AOP is ammonium orthophosphate and APP is ammonium polyphosphate.

Table XII. Effects of P rate, P carrier, and Zn rate on corn plant yield and composition in the growth chamber (Irsik east soil).

Treatments			First Crop				Second Crop			
P	P	Zn	Yield		Plant		Yield		Plant	
ppm	Carrier	ppm	Fresh	Dry	Composition		Fresh	Dry	Composition	
			g/pot	g/pot	%P	ppm Zn	g/pot	g/pot	%P	ppm Zn
0	---	0	15.1	1.4	0.22	16.8	24.8	2.2	0.27	12.6
20	AOP ^{a/}	0	26.4	2.6	0.22	9.7	30.0	2.9	0.28	9.4
40	AOP	0	28.7	2.6	0.23	7.5	26.3	2.2	0.34	14.0
80	AOP	0	35.1	3.2	0.30	6.7	29.8	2.8	0.38	9.4
20	APP	0	23.2	2.2	0.21	9.3	29.8	2.9	0.28	9.5
40	APP	0	27.3	2.5	0.23	8.6	30.4	2.7	0.32	9.7
80	APP	0	34.5	3.4	0.30	7.5	30.4	2.2	0.41	8.2
20	AOP	8	28.2	2.8	0.19	18.2	31.6	3.2	0.29	18.2
40	AOP	8	32.4	3.1	0.22	20.8	30.3	3.0	0.29	16.4
80	AOP	8	35.9	3.4	0.27	18.4	33.1	3.5	0.31	17.9
20	APP	8	26.1	2.4	0.22	28.4	24.8	2.1	0.32	24.9
40	APP	8	29.9	3.0	0.21	22.9	25.2	2.2	0.32	17.8
80	APP	8	34.3	3.6	0.27	19.9	32.5	3.3	0.30	17.3
Treatment LSD _{.05}			5.7	0.8	0.05	6.1	4.2	0.7	0.05	6.3
Mean Values										
P rate			20	26.0	2.5	0.21	16.4	29.0	2.8	0.29
			40	29.6	2.8	0.22	15.0	28.0	2.5	0.32
			80	34.9	3.4	0.29	13.1	31.4	2.9	0.35
LSD _{.05}				3.0	0.4	0.03	NS	2.0	NS	0.03
P carrier										
			APP	29.2	2.8	0.24	16.1	28.8	2.6	0.33
			AOP	31.1	2.9	0.24	13.6	30.2	2.9	0.31
LSD _{.05}				NS	NS	NS	2.4	NS	0.3	NS
Zn rate			0	29.2	2.7	0.25	8.2	29.4	2.6	0.34
			8	31.1	3.1	0.23	21.4	29.6	2.9	0.30
LSD _{.05}				NS	NS	NS	2.4	NS	NS	0.02

^{a/} AOP is ammonium orthophosphate and APP is ammonium polyphosphate.

Table XIII. Effects of P rate, P carrier, and Zn rate on corn plant yield and composition in the growth chamber (Sisk and Cotter soils).

Treatments			Sisk Soil				Cotter Soil			
			Yield		Plant		Yield		Plant	
P ppm	P Carrier	Zn ppm	Fresh g/pot	Dry g/pot	Composition %P	ppm Zn	Fresh g/pot	Dry g/pot	Composition %P	ppm Zn
0	---	0	19.6	2.0	0.25	43.2	16.1	1.7	0.26	39.5
20	AOP ^{a/}	0	25.7	2.7	0.27	38.5	18.9	1.9	0.35	38.9
40	AOP	0	29.7	3.1	0.29	36.5	17.2	1.7	0.38	37.0
80	AOP	0	33.6	3.4	0.33	28.2	24.9	2.3	0.43	35.5
20	APP	0	25.1	2.5	0.29	40.0	20.4	1.9	0.34	43.5
40	APP	0	27.3	3.0	0.28	35.1	25.4	2.4	0.35	42.0
80	APP	0	34.4	3.7	0.33	30.2	26.4	2.6	0.48	37.5
0	---	8	20.8	2.1	0.28	63.1	14.4	1.5	0.29	63.8
20	AOP	8	26.2	2.7	0.28	56.5	16.5	1.6	0.36	56.0
40	AOP	8	30.6	3.3	0.29	47.7	22.3	2.2	0.31	59.2
80	AOP	8	34.1	3.6	0.36	41.9	26.6	2.6	0.31	56.0
20	APP	8	27.8	2.9	0.29	54.3	19.4	1.9	0.25	61.0
40	APP	8	31.2	3.3	0.30	53.6	23.7	2.2	0.29	55.6
80	APP	8	32.6	3.6	0.34	58.6	26.5	2.5	0.31	57.0
Treatment LSD _{.05}			3.9	0.4	0.03	13.3	3.5	0.4	0.04	11.0
Mean Values										
P rate		20	26.2	2.7	0.28	47.3	18.8	1.8	0.33	49.8
		40	29.7	3.2	0.29	43.2	22.2	2.1	0.33	48.5
		80	33.7	3.6	0.34	39.7	26.1	2.5	0.38	46.5
LSD _{.05}			2.0	0.2	0.01	NS	1.8	0.2	0.02	NS
P carrier										
		APP	29.7	3.2	0.31	45.3	23.6	2.3	0.34	49.5
		AOP	30.0	3.1	0.30	41.6	21.1	2.1	0.36	47.1
LSD _{.05}			NS	NS	NS	NS	1.5	0.2	0.02	NS
Zn rate		0	29.3	3.1	0.30	34.8	22.2	2.1	0.39	39.1
		8	30.4	3.2	0.31	52.1	22.5	2.2	0.31	57.5
LSD _{.05}			NS	NS	NS	5.7	NS	NS	0.02	3.5

^{a/} AOP is ammonium orthophosphate and APP is ammonium polyphosphate.

Table XIV. Effects of P rate, P carrier, and Zn rate on corn plant yield and composition in the growth chamber (Burr Oak soil).

Treatments			Yield		Plant Composition	
P ppm	P Carrier	Zn ppm	Fresh g/pot	Dry g/pot	%P	ppm Zn
0	---	0	16.8	1.7	0.20	16.4
20	AOP ^{a/}	0	20.0	2.1	0.22	18.2
40	AOP	0	24.9	2.9	0.21	12.7
80	AOP	0	25.7	2.9	0.22	10.6
20	APP	0	21.7	2.3	0.22	16.0
40	APP	0	24.9	2.7	0.22	11.6
80	APP	0	25.8	2.9	0.21	11.7
0	---	8	19.5	2.0	0.20	54.8
20	AOP	8	23.2	2.5	0.20	47.5
40	AOP	8	23.2	2.7	0.20	44.2
80	AOP	8	26.3	3.2	0.20	37.4
20	APP	8	21.8	2.3	0.22	49.1
40	APP	8	25.2	2.9	0.21	35.3
80	APP	8	26.2	3.0	0.21	39.8
Treatment LSD _{.05}			3.0	0.6	NS	7.3
Mean Values						
P rate	20		21.7	2.3	0.21	32.7
	40		24.6	2.8	0.21	25.9
	80		26.0	3.0	0.21	24.9
LSD _{.05}			1.5	0.3	NS	3.7
P carrier						
	APP		24.3	2.7	0.21	27.3
	AOP		23.9	2.7	0.21	28.4
LSD _{.05}			NS	NS	NS	NS
Zn rate	0		23.8	2.6	0.22	13.5
	8		24.3	2.8	0.21	42.2
LSD _{.05}			NS	NS	NS	3.0

^{a/} AOP is ammonium orthophosphate and APP is ammonium polyphosphate.

Table XV. Effects of P rate, P carrier, and Zn rate on soil available P and extractable Zn in the growth chamber (Tribune and Irsik west soils).

P ppm	Treatments P Carrier	Zn ppm	Tribune Soil				Irsik West Soil			
			First Crop ^{a/}		Second Crop ^{a/}		First Crop		Second Crop	
			P kg/ha	Zn ppm	P kg/ha	Zn ppm	P kg/ha	Zn ppm	P kg/ha	Zn ppm
0	---	0	46	0.70	30	0.81	20	0.52	9	0.49
20	AOP ^{b/}	0	58	0.70	45	0.92	28	0.45	12	0.51
40	AOP	0	87	0.60	62	0.80	40	0.39	22	0.61
80	AOP	0	124	0.88	93	0.86	60	0.53	26	0.56
20	APP	0	68	0.78	48	1.03	29	0.55	11	0.51
40	APP	0	80	0.73	63	0.93	50	0.44	21	0.49
80	APP	0	106	0.81	100	0.84	55	0.60	34	0.49
20	AOP	8	59	3.43	44	4.58	30	2.89	13	3.20
40	AOP	8	74	3.19	63	4.23	47	3.16	25	3.47
80	AOP	8	116	3.11	101	4.73	82	2.58	52	3.48
20	APP	8	53	3.46	49	3.63	29	2.64	18	3.35
40	APP	8	77	4.10	68	3.63	48	2.60	27	3.13
80	APP	8	129	3.39	78	4.01	67	2.30	45	3.74
Treatment LSD _{.05}			19	0.34	17	1.16	20	0.74	20	1.16
Mean Values										
P rate		20	60	2.09	46	2.54	29	1.64	13	1.89
		40	80	2.16	64	2.40	46	1.65	24	1.93
		80	119	2.05	93	2.61	66	1.50	38	2.07
LSD _{.05}			10	NS	9	NS	10	NS	10	NS
P carrier										
		APP	85	2.21	68	2.34	47	1.52	26	1.95
		AOP	87	1.98	67	2.69	48	1.67	25	1.97
LSD _{.05}			NS	0.15	NS	NS	NS	NS	NS	NS
Zn rate		0	87	0.75	68	0.90	44	0.50	21	0.52
		8	85	3.45	67	4.14	50	2.69	30	3.40
LSD _{.05}			NS	0.15	NS	0.48	NS	0.31	8	0.49

a/ First crop denotes soil sampled after harvest of first crop, second crop denotes soil sampled after harvest of second crop.

b/ AOP is ammonium orthophosphate and APP is ammonium polyphosphate.

Table XVI. Effects of P rate, P carrier, and Zn rate on soil available P and extractable Zn in the growth chamber (Irsik east soil).

P ppm	Treatments		Zn ppm	First Crop ^{a/}		Second Crop ^{a/}	
	P Carrier			P kg/ha	Zn ppm	P kg/ha	Zn ppm
0	---		0	30	0.62	20	0.76
20	AOP ^{b/}		0	47	0.87	32	0.73
40	AOP		0	73	0.80	55	0.73
80	AOP		0	116	0.76	102	0.68
20	APP		0	49	0.71	53	0.74
40	APP		0	78	0.49	59	0.73
80	APP		0	83	0.85	90	0.72
20	AOP		8	36	2.19	34	3.22
40	AOP		8	66	3.17	57	3.11
80	AOP		8	95	2.98	97	3.09
20	APP		8	48	4.70	37	3.88
40	APP		8	67	3.70	55	3.80
80	APP		8	110	3.92	99	3.41
Treatment LSD _{.05}				37	1.08	24	0.89
Mean Values							
P rate		20		45	2.11	39	2.14
		40		72	2.04	56	2.09
		80		101	2.13	97	1.97
LSD _{.05}				19	NS	12	NS
P carrier							
		APP		73	2.39	66	2.21
		AOP		72	1.79	63	1.92
LSD _{.05}				NS	0.45	NS	NS
Zn rate		0		75	0.75	65	0.72
		8		71	3.44	63	3.42
LSD _{.05}				NS	0.45	NS	0.38

^{a/} First crop denotes soil sampled after harvest of first crop and second crop denotes soil sampled after harvest of second crop.

^{b/} AOP is ammonium orthophosphate and APP is ammonium polyphosphate.

Table XVII. Effects of P rate, P carrier, and Zn rate on soil available P and extractable Zn in the growth chamber (Sisk, Cotter, and Burr Oak soils).

Treatments			Sisk Soil		Cotter Soil		Burr Oak Soil	
P	P	Zn	P	Zn	P	Zn	P	Zn
ppm	Carrier	ppm	kg/ha	ppm	kg/ha	ppm	kg/ha	ppm
0	---	0	55	2.29	46	1.53	10	0.85
20	AOP ^{a/}	0	69	2.22	63	1.48	18	0.65
40	AOP	0	90	2.33	78	1.34	30	0.69
80	AOP	0	115	2.48	114	1.48	47	0.68
20	APP	0	67	2.19	65	1.65	22	0.66
40	APP	0	88	2.13	80	3.38	35	0.70
80	APP	0	116	2.28	120	1.42	37	0.74
0	---	8	54	5.61	49	3.93	15	4.63
20	AOP	8	72	4.79	58	3.67	13	5.15
40	AOP	8	91	5.12	58	3.61	24	5.31
80	AOP	8	123	4.66	92	3.34	35	5.31
20	APP	8	71	5.45	38	3.23	15	4.45
40	APP	8	81	4.92	55	3.65	16	4.01
80	APP	8	121	4.77	74	3.28	35	6.01
Treatment LSD _{.05}			13	0.57	11	1.42	16	0.85
Mean Values								
P rate			69	3.66	56	2.51	17	2.73
40			87	3.63	68	3.00	26	2.68
80			119	3.55	100	2.38	38	3.19
LSD _{.05}			8	NS	6	NS	9	0.38
P carrier								
APP			91	3.62	72	2.77	27	2.76
AOP			93	3.59	77	2.49	28	2.97
LSD _{.05}			NS	NS	4	NS	NS	NS
Zn rate			91	2.27	86	1.79	31	0.69
8			93	4.95	63	3.46	22	5.04
LSD _{.05}			NS	0.25	4	0.62	7	0.31

^{a/} AOP is ammonium orthophosphate and APP is ammonium polyphosphate.

COMPARATIVE PERFORMANCE OF POLYPHOSPHATE
FERTILIZERS FOR THREE ROW CROPS

by

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Two types of field studies were conducted in 1974 and 1975 to evaluate the performance of several phosphorus carriers as P sources for irrigated crops on high pH soils in western Kansas. One type of study compared ammonium polyphosphate (APP) and ammonium orthophosphate (AOP) with and without zinc applications using corn (Zea mays L.), grain sorghum (Sorghum bicolor), and soybeans (Glycine max) as test crops. The other type of study compared AOP, APP, APP plus ethylenediamine tetracetate (EDTA), potassium polyphosphate (KPP), sodium tripolyphosphate (NaTPP), and urea ammonium polyphosphate (UAPP) as P sources for corn and grain sorghum. Phosphorus rates in the first study were 20, 40, and 60 kg P/ha with zinc rates of 4.5 or 9 kg Zn/ha as ZnO, ZnSO₄, or Zn-NH₃ complex depending upon the year and location. The second type of study involved P rates of 20 and 40 kg P/ha with a blanket application of 3.4 or 4.5 kg Zn/ha as either Zn EDTA or Zn-NH₃ complex depending on the year and location.

In addition to the field studies, growth chamber comparisons of AOP and APP using soils from several Kansas field sites and from the Mississippi River Delta region of northeastern Arkansas and western Tennessee were performed. Rates of applied P were 20, 40, and 80 ppm P with a Zn variable of 8 ppm Zn as ZnO.

Positive grain yield and leaf P concentration responses to applied P were observed in many of the field studies. Differences among P carriers, however, were few. Occasionally, either AOP or APP would show slightly superior effects, but the differences were small and usually not statistically significant at the 5% level. Only once did APP increase the Zn concentration in the plant over AOP, but this difference was slight and not statistically significant. Soil applications of Zn frequently increased Zn concentrations in plant tissue, but had little effect on yields.

Growth chamber studies frequently recorded increased plant dry matter production and higher P concentrations from P applications. Phosphorus

carrier differences were almost nonexistent except for influences on plant Zn concentrations. Several increases in Zn concentrations were noted with the use of APP as compared to AOP regardless of whether zinc was applied or not. With one soil, however, the use of APP increased Zn concentrations over AOP only when Zn was applied. When this soil was analyzed for DTPA-extractable Zn, the application of APP in conjunction with Zn application increased the available soil Zn more than when AOP was used with Zn application. Good increases in Zn concentration in corn plants were obtained by adding 8 ppm Zn to the soil under growth chamber conditions.